Silicon II: MAPS

Physics, Technology, Status, Plans

Michael P. McCumber
Los Alamos National Laboratory

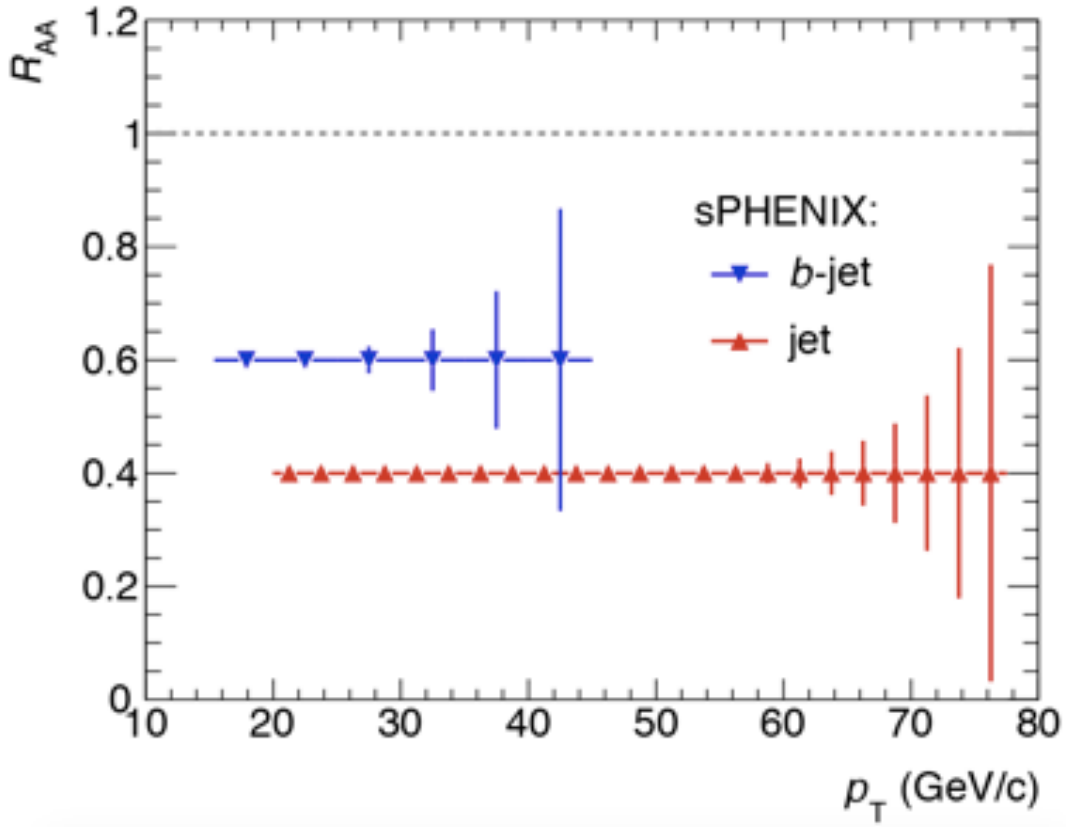
2nd sPHENIX Collaboration Meeting

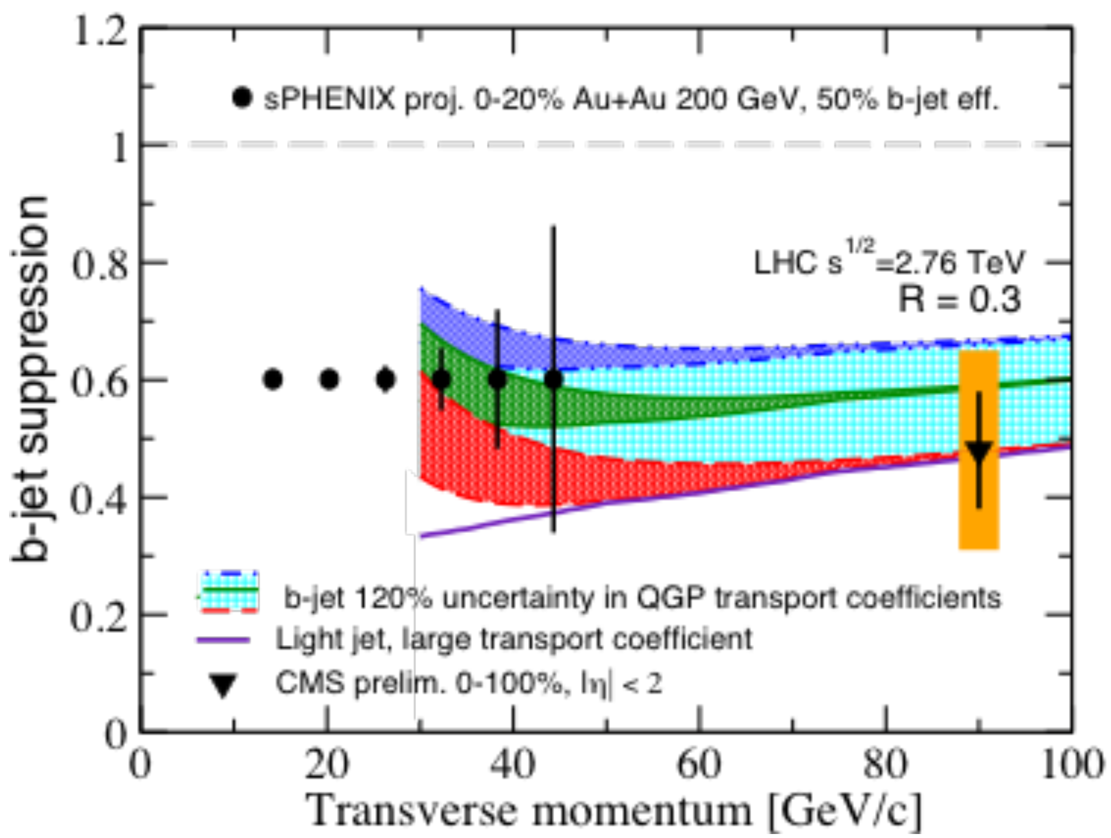
from Wednesday, May 18, 2016 at **09:00** to Friday, May 20, 2016 at **18:00** (US/Eastern)
at **BNL (Large Seminar Room)**

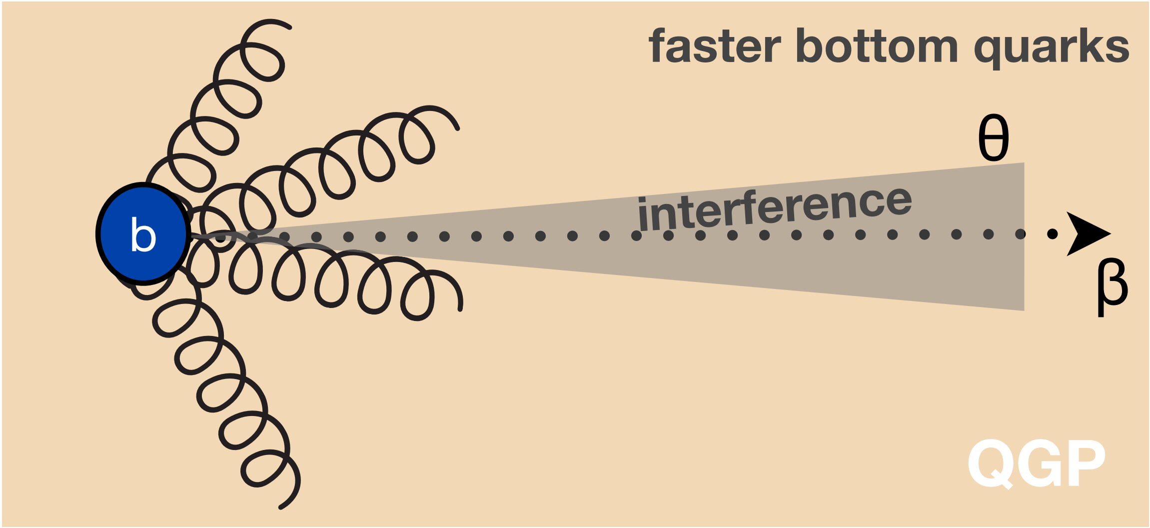
sPHENIX

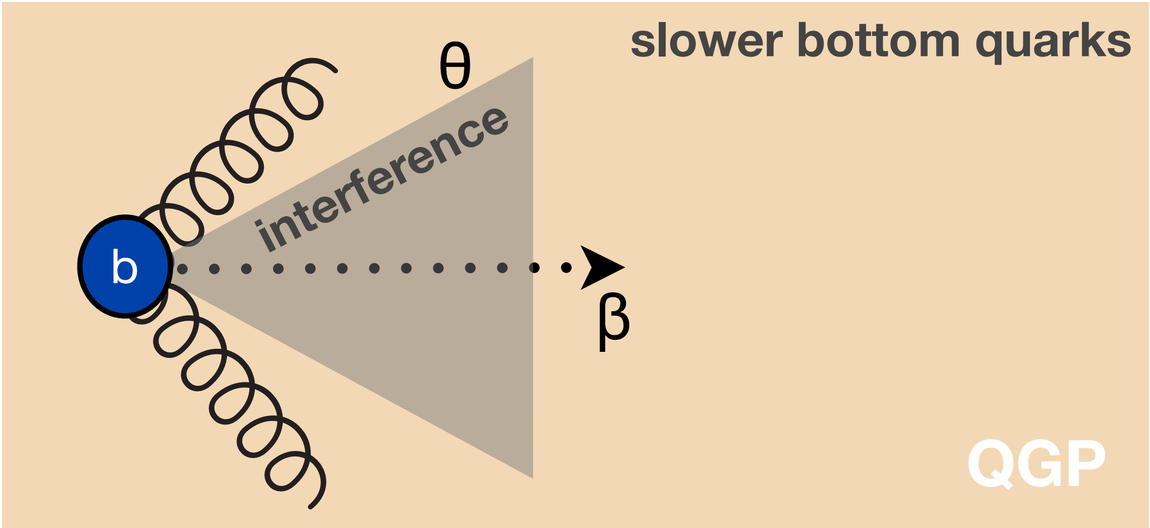
Los Alamos
NATIONAL LABORATORY
EST. 1943

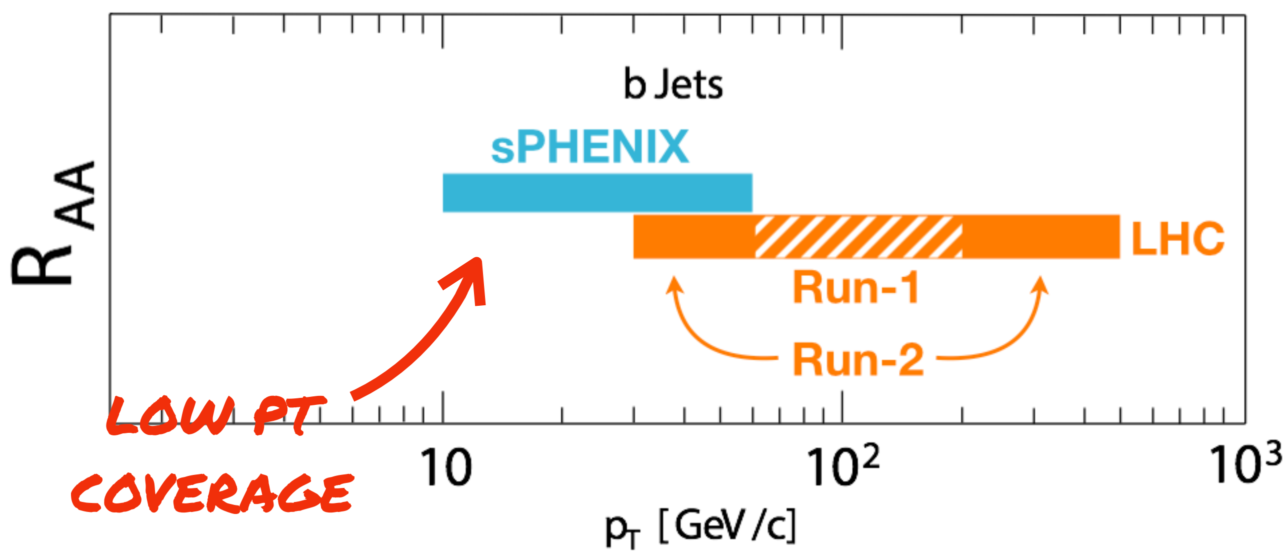
B-jet Physics: Energy Loss



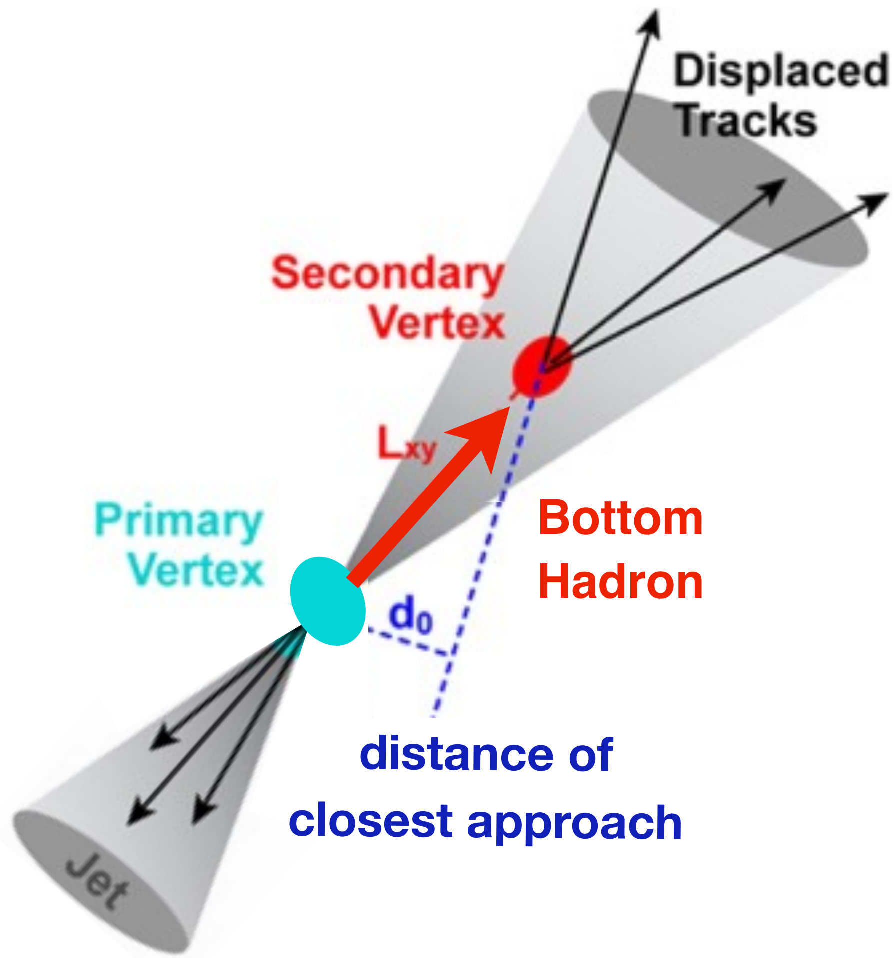








B-jet Identification Methodology



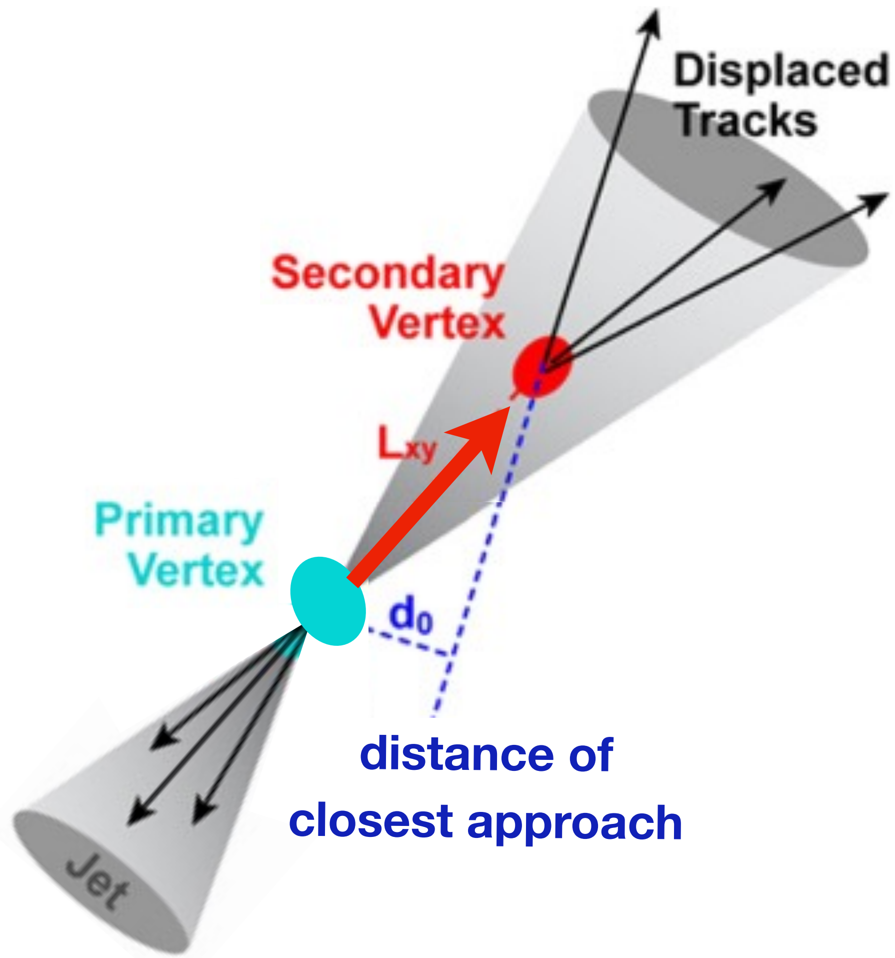
sPHENIX should have access to 3 different techniques for heavy-flavor identification:

(1) Semi-leptonic decay
(2) Multiple Large DCA tracks
(3) Secondary Vertex Mass

Big push from DVP
for sPHENIX proposal

Unexplored thus far!

Track-Counting Technique



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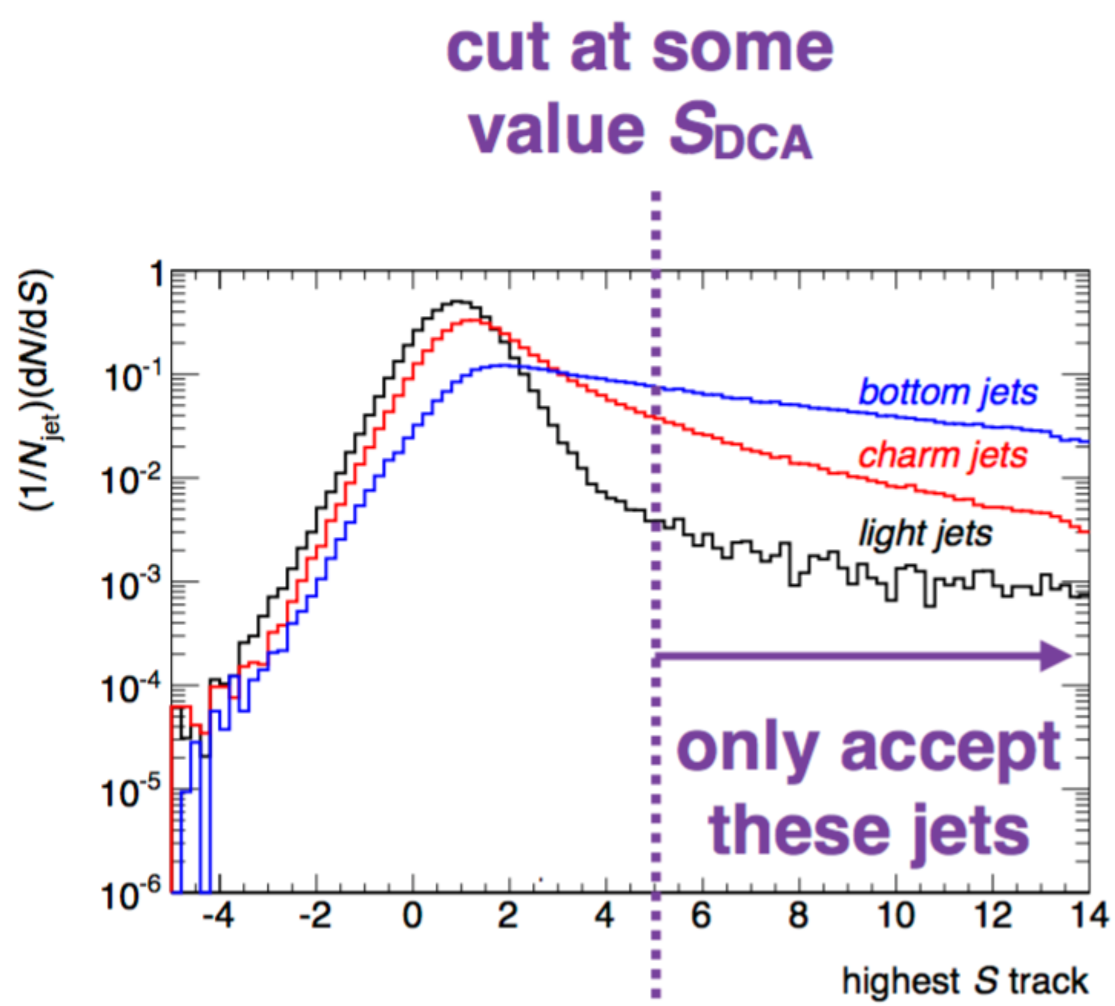


Track Counting requirements:

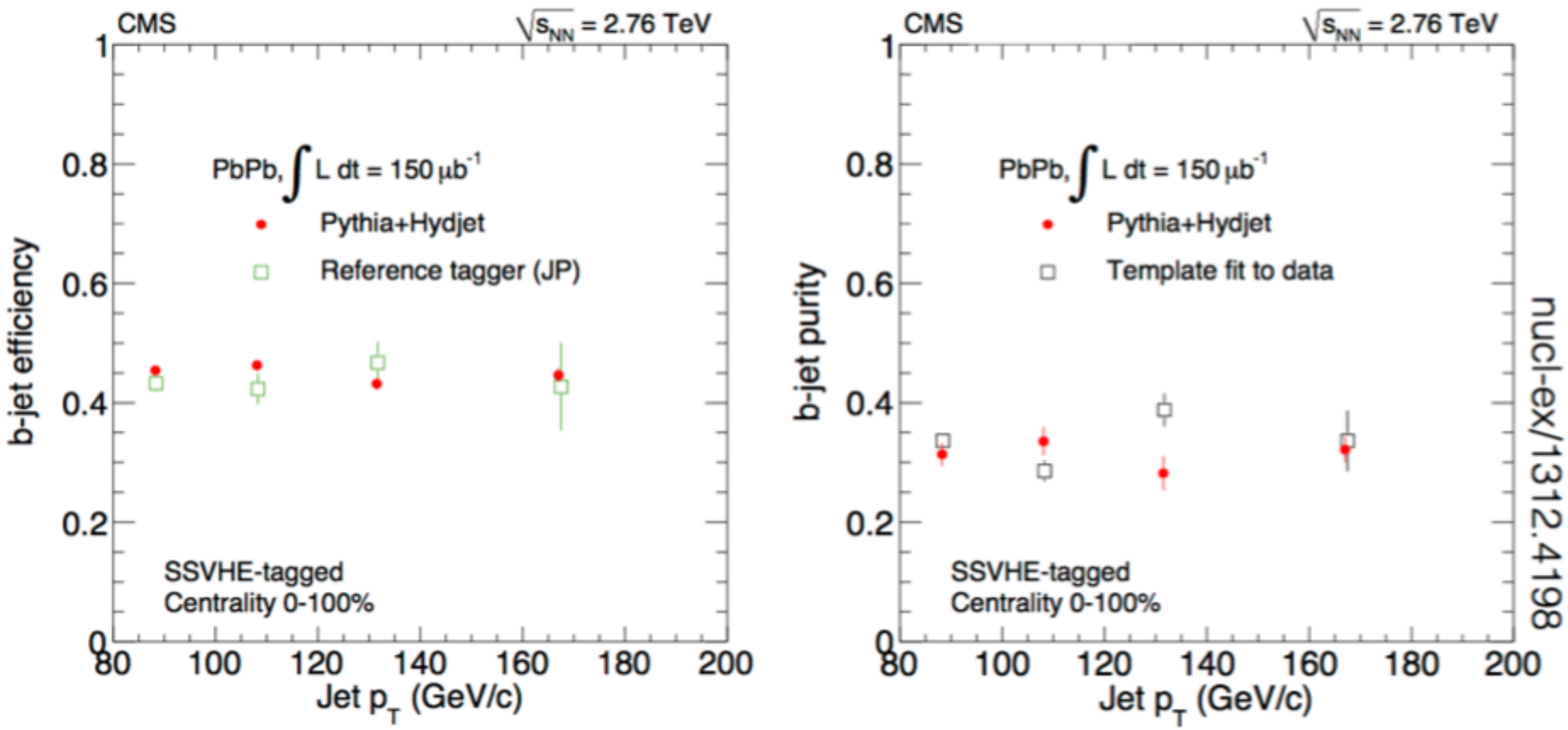
Large single particle reconstruction efficiency, ~ϵ^N

Narrow primary hadron DCA distribution (<70um)

CMS b-jet Performance

from the April Review…

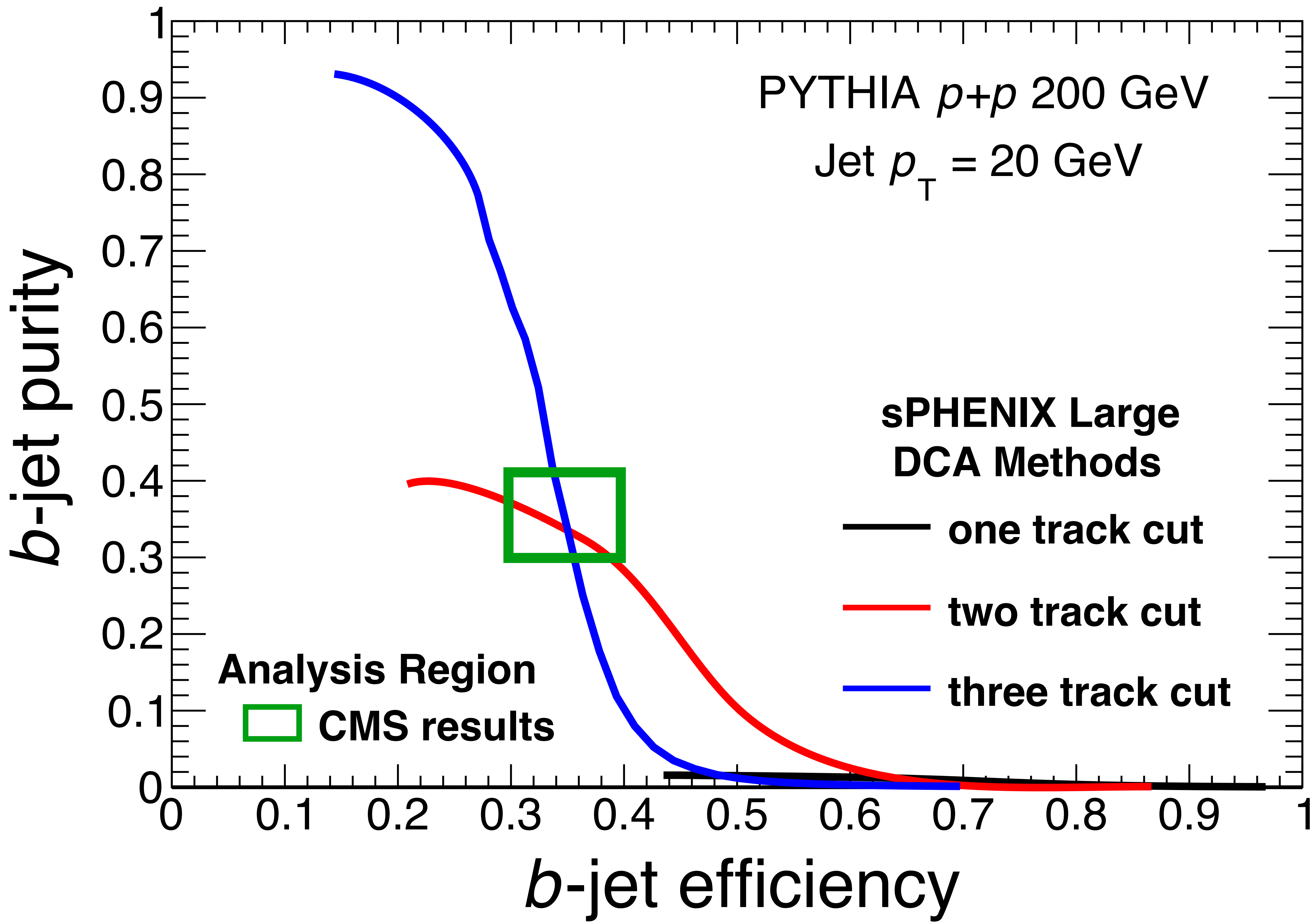
b-jet efficiency and purity in Pb+Pb



≈45% Efficiency and *≈35% Purity* in the CMS *b*-jet spectrum in Pb+Pb

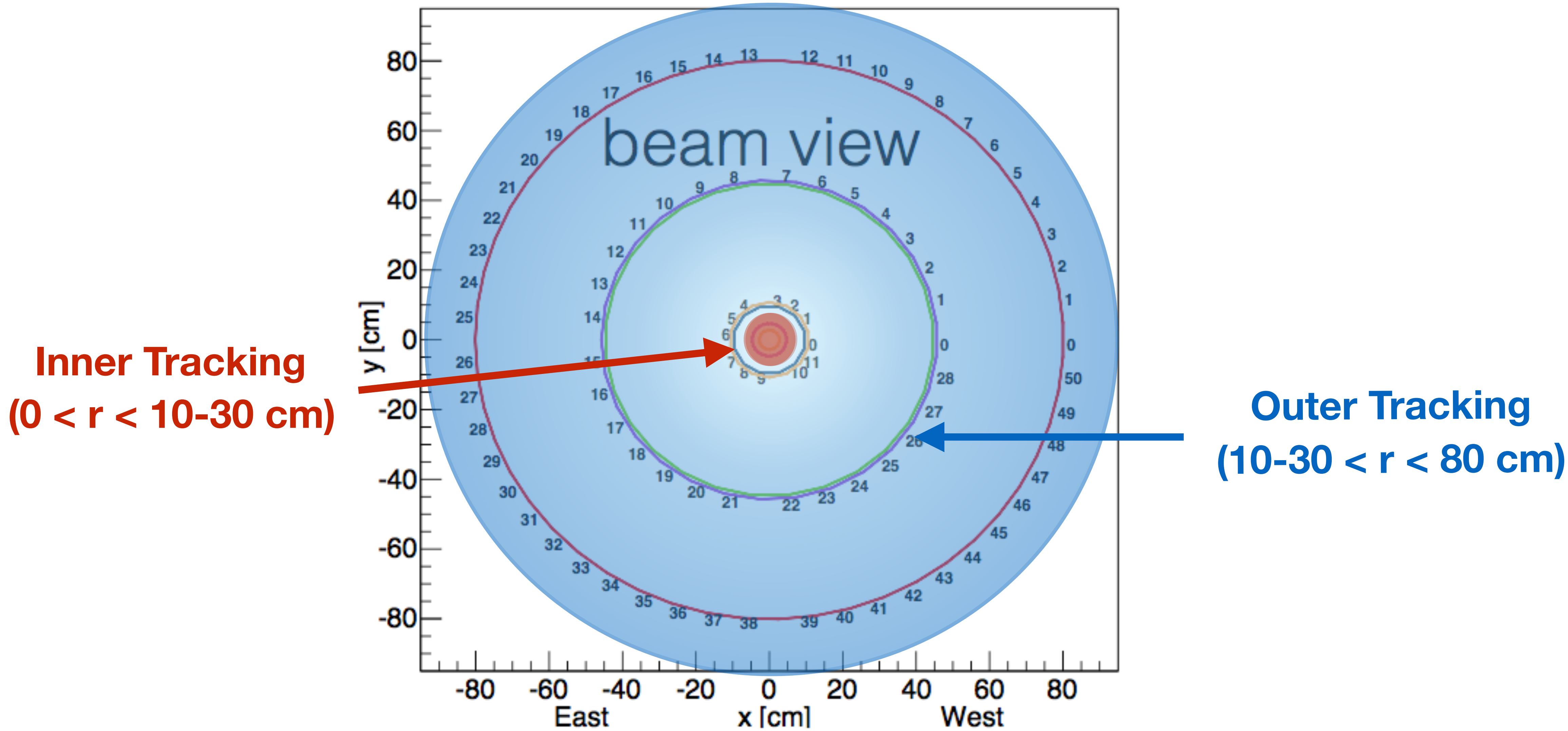
➡ comparable to that achievable with 2- or 3-track TrackCounting cuts

b-jet Identification Trade-Off



NB: under the assumption of 100% single particle efficiency!!!

Partial Factorization: Tracking Goals



Inner tracking:

(1) precision track position (DCA, 2nd vertexing)

(2) high resolution collision vertexing

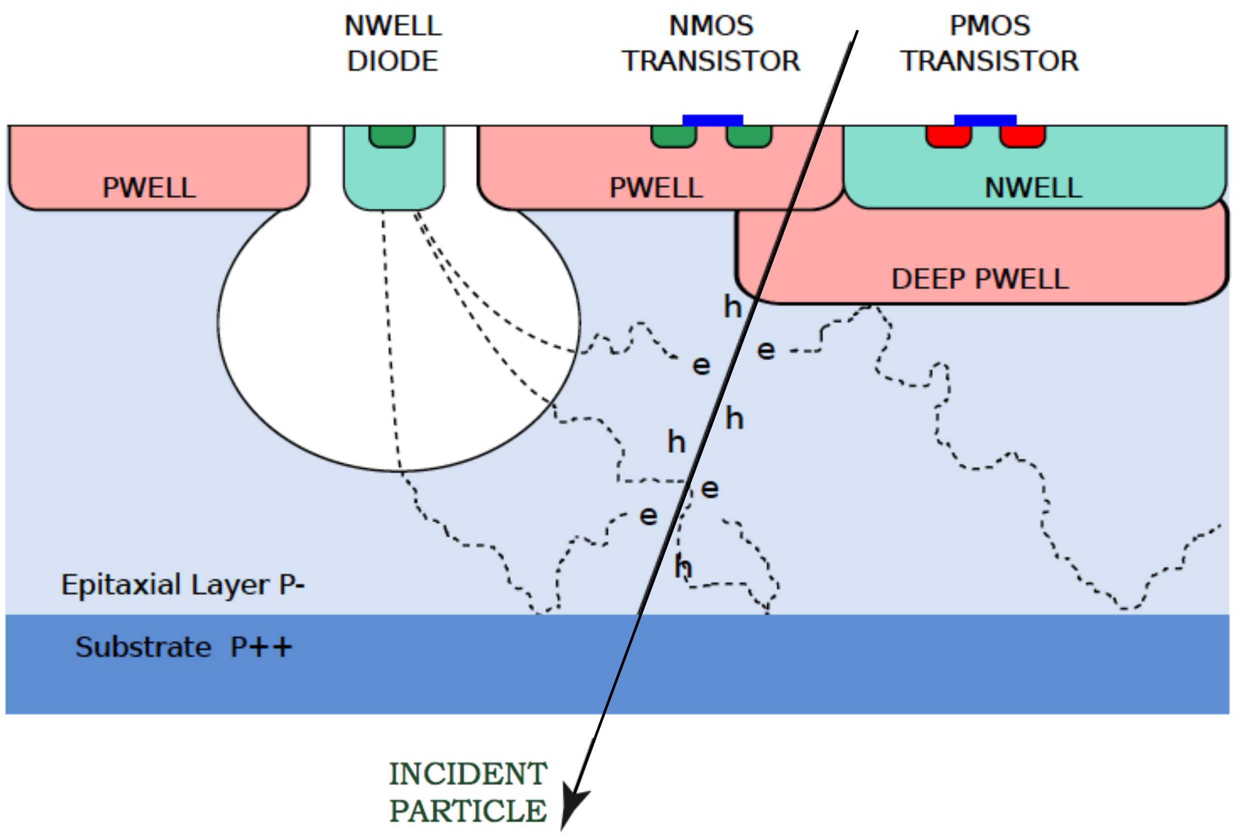
(3) pattern recognition ambiguity breaking

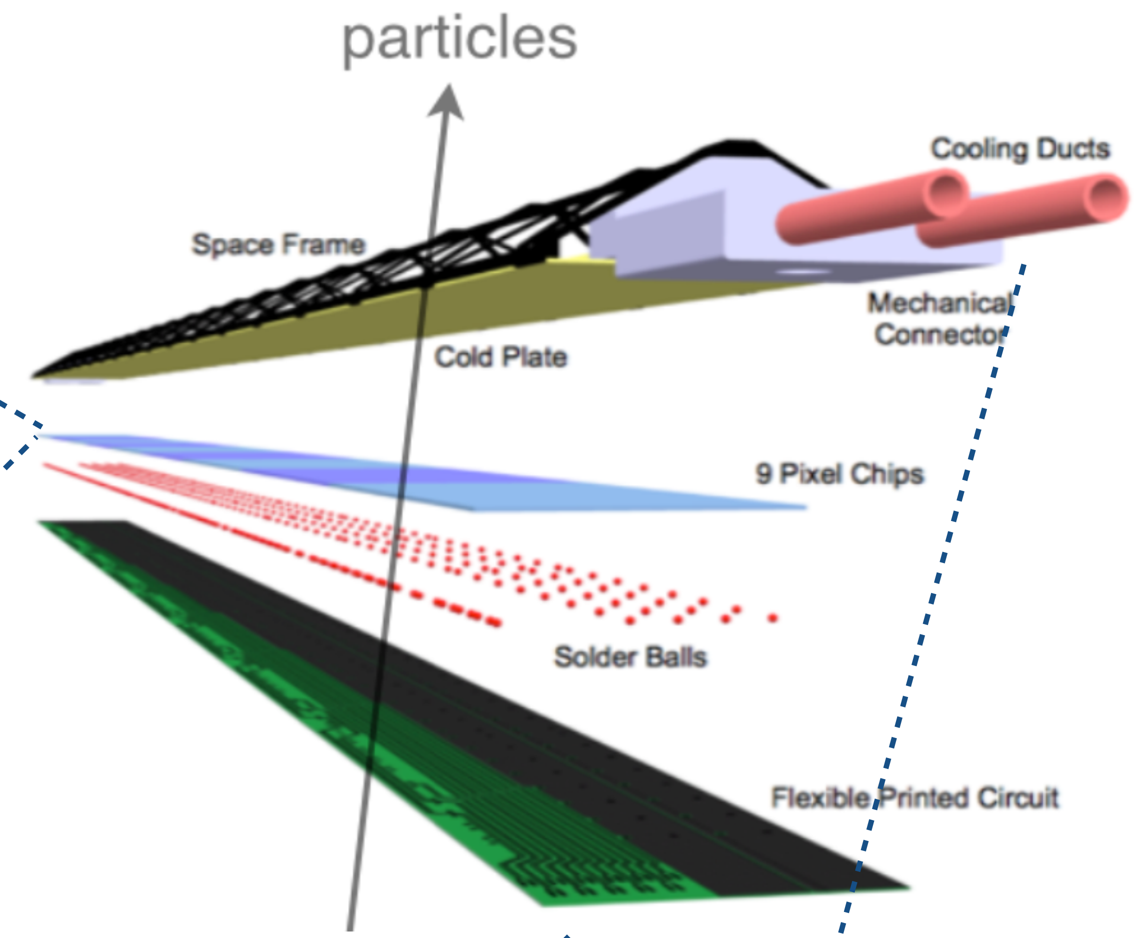
Outer tracking:

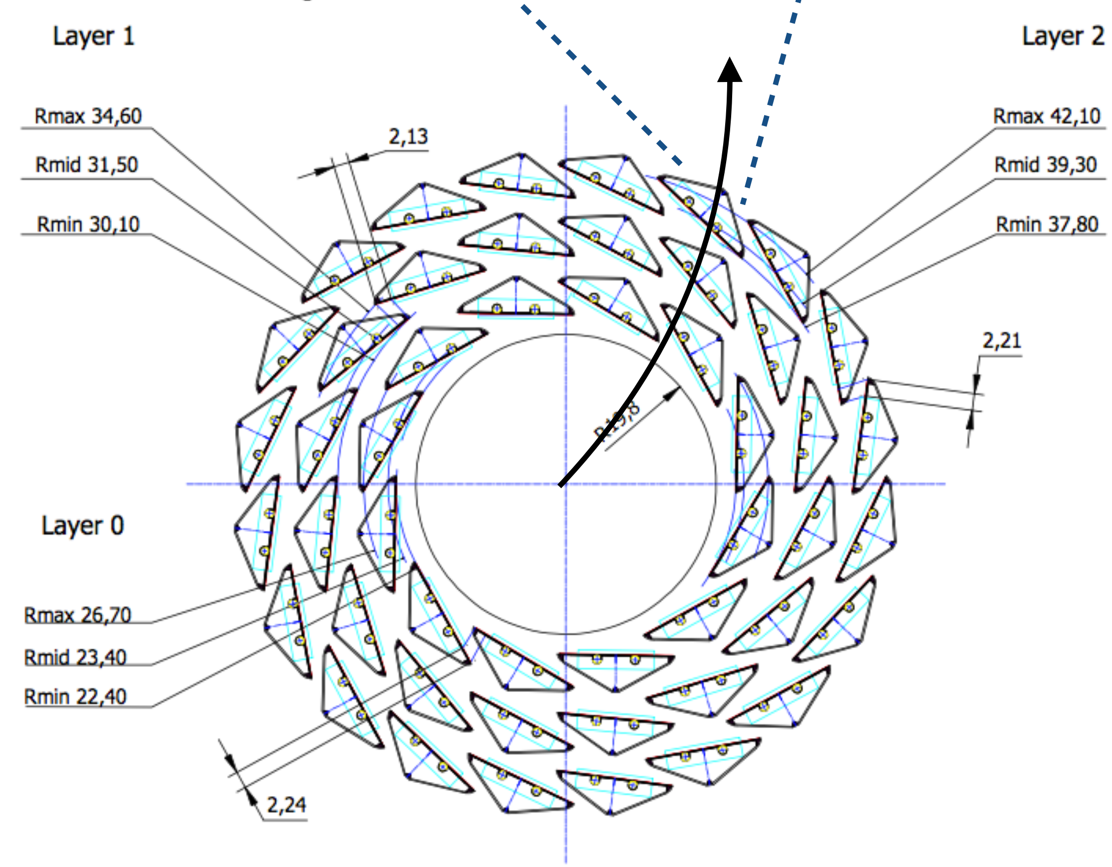
(1) momentum resolution optimization

(2) pattern recognition ambiguity breaking

Inner Tracking with MAPS sensors







Inner Silicon Concept:

Thin, fine pitch (<30 um), large efficiency (99.9…%)
Optimizations for material thickness, ~0.3%/layer
Integration time: ~2-4 us

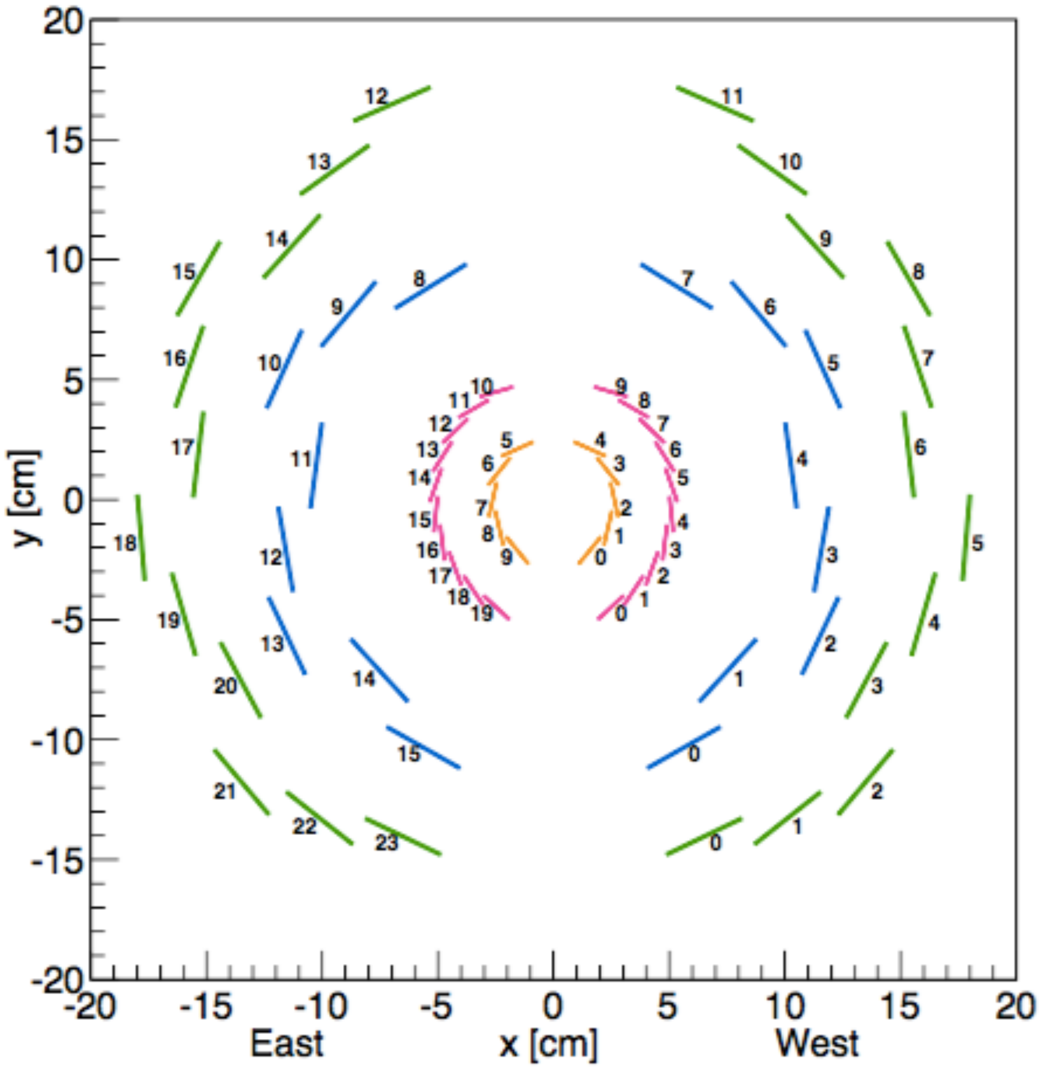
Goal:

Precision tracking & vertexing for b-jet identification and other tracking duties

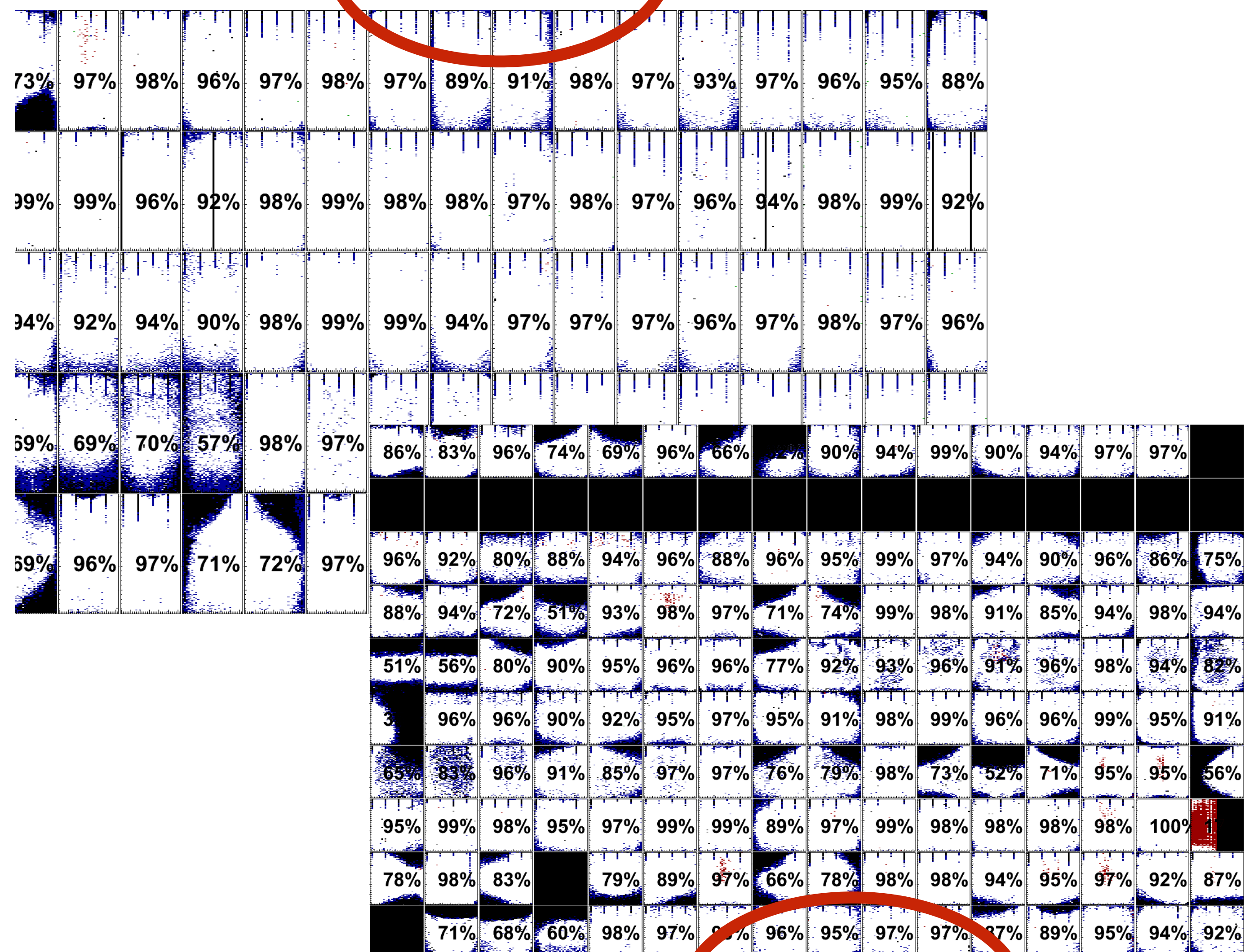
Opportunity:

Reuse thin inner tracking layers during the EIC era

Tracking Option: VTX Pixels



Pixel Layer 1, 92.5% Active



Pixel Layer 2, 72.5% Active

Station	Layer	radius (cm)	pitch (μm)	sensor length (cm)	depth (μm)	total thickness X_0%	area (m^2)
Pixel	1	2.4	50	0.425	200	1.3	0.034
Pixel	2	4.4	50	0.425	200	1.3	0.059
S0a	3	7.5	58	9.6	240	1.0	0.18

Aside: Other Potential Pixel Reuse Pitfalls

Material thickness (1.3% per layer):

More clear now that with the strip outer layers the material in the inner layers isn't a driver on the Upsilon separation, we should repeat that with the TPC option

Long term evolution will still replace the pixels

One-dimensional optimization in pitch (50um x 425um):

VTX pixels were designed around a DCA-based analysis

Two track intersection probabilities needed for 2nd vertex reconstruction need to be understood

Can the VTX pixels perform the 2nd vertex reconstruction at all?

DAQ Rate:

VTX pixel test saw 14 kHz at 60% live time, somewhat under our 15 kHz ~90% live time readout spec

New hardware could design in the full readout bandwidth

Not sure where the next bottleneck would be, more than a small gain?

Limited TPC integration flexibility:

A finite surface area of VTX pixels is available, we can cover 2.5 cm and 3.6 cm, **no spares**

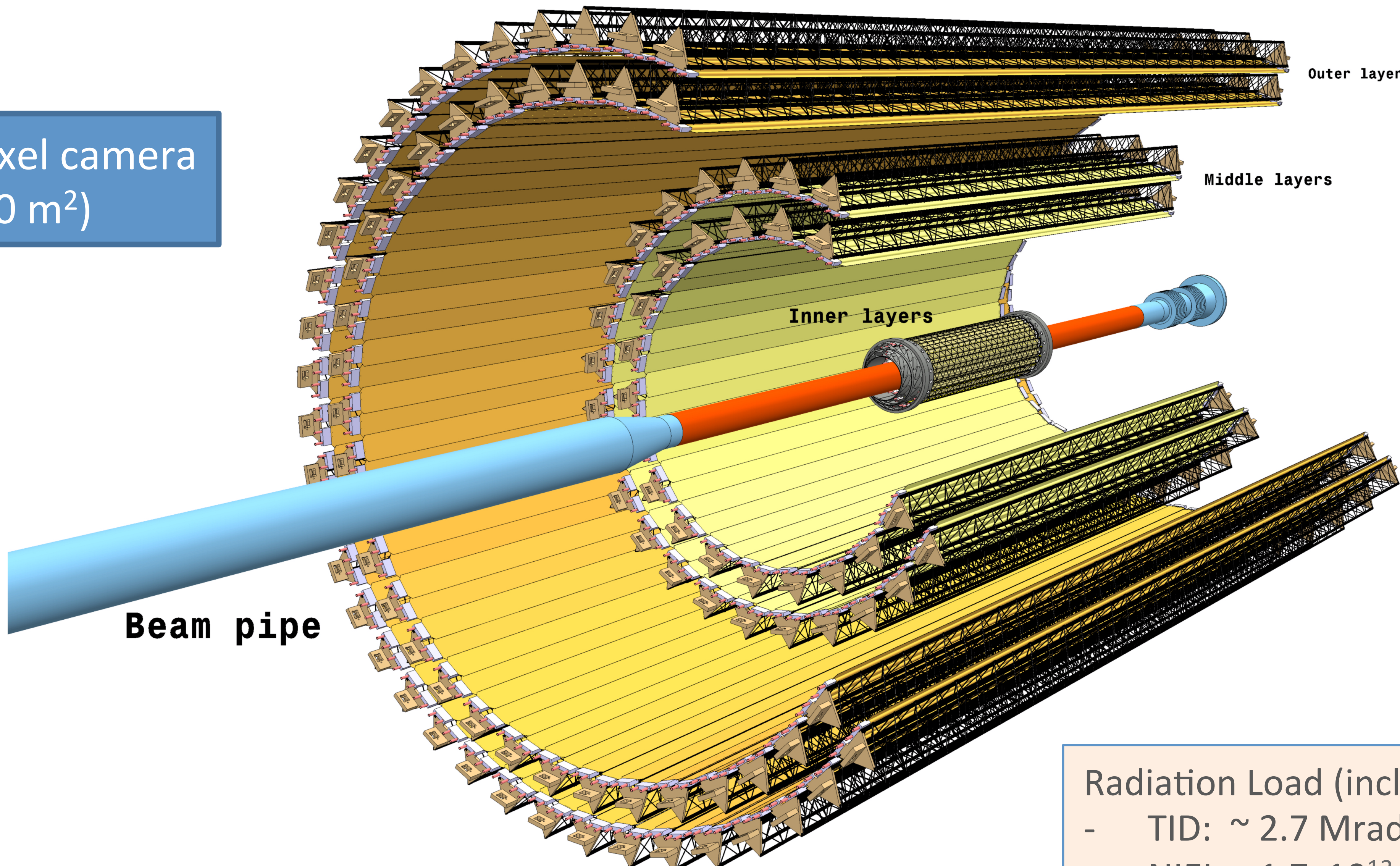
TPC based tracking starts no closer than 30 cm

3.6 cm to 30 cm is a long jump to make

We may need a tracking layer between 4.4 and 30 cm to break ambiguities in the tracking

ALICE ITS Upgrade

12.5 G-pixel camera
(~10 m^2)



Radiation Load (incl. safety factor 10)
- TID: ~ 2.7 Mrad
- NIEL: ~1.7×10^{13} 1MeV n_{eq} / cm^2

7-layer barrel geometry based on CMOS Sensors

r coverage: 23 – 400 mm

η coverage: $|\eta| \leq 1.22$
for tracks from 90% most luminous region

3 Inner Barrel layers (**IB**)

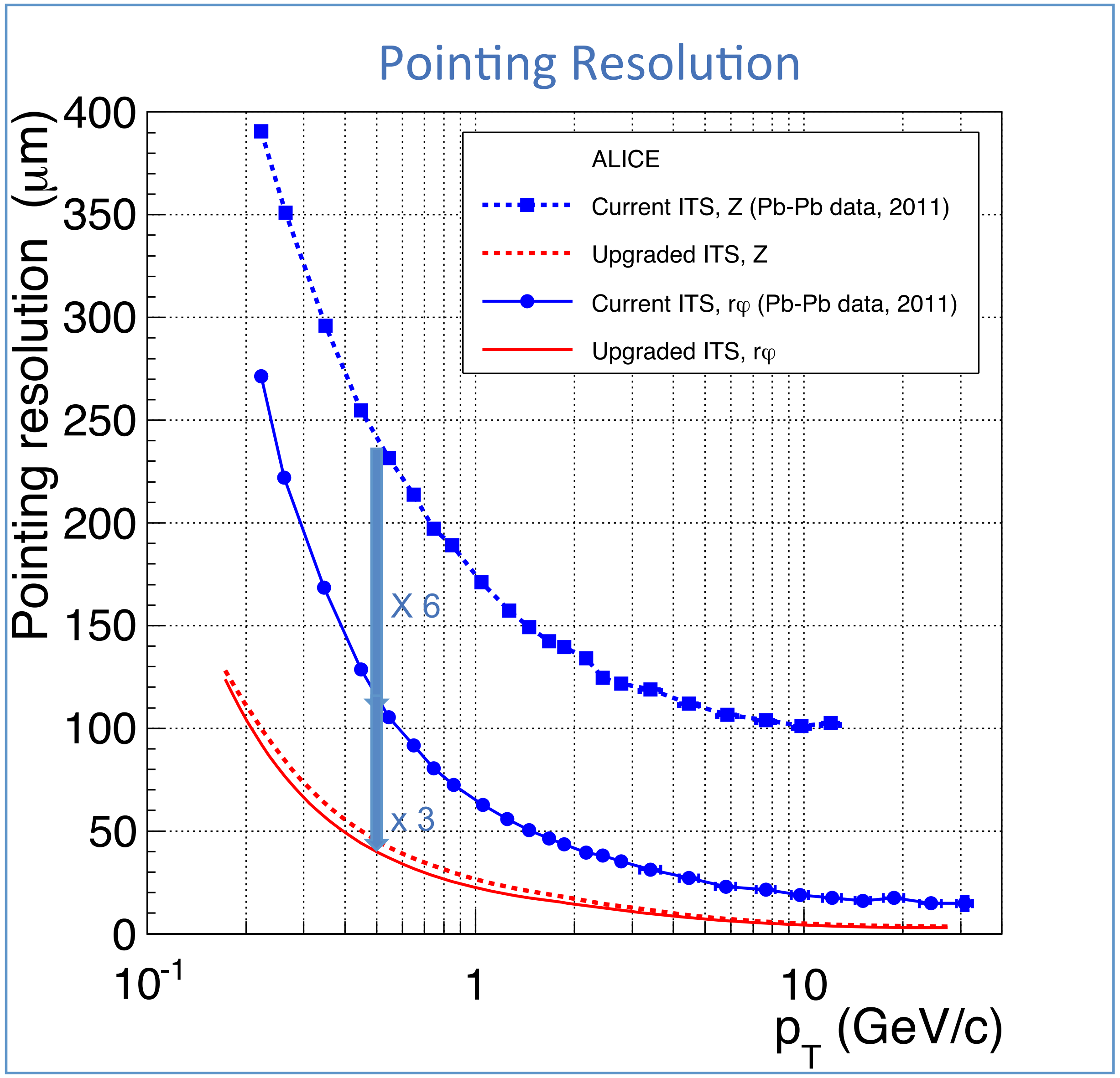
4 Outer Barrel layers (**OB**)

Material /layer : 0.3% X_0 (IB), 1% X_0 (OB)

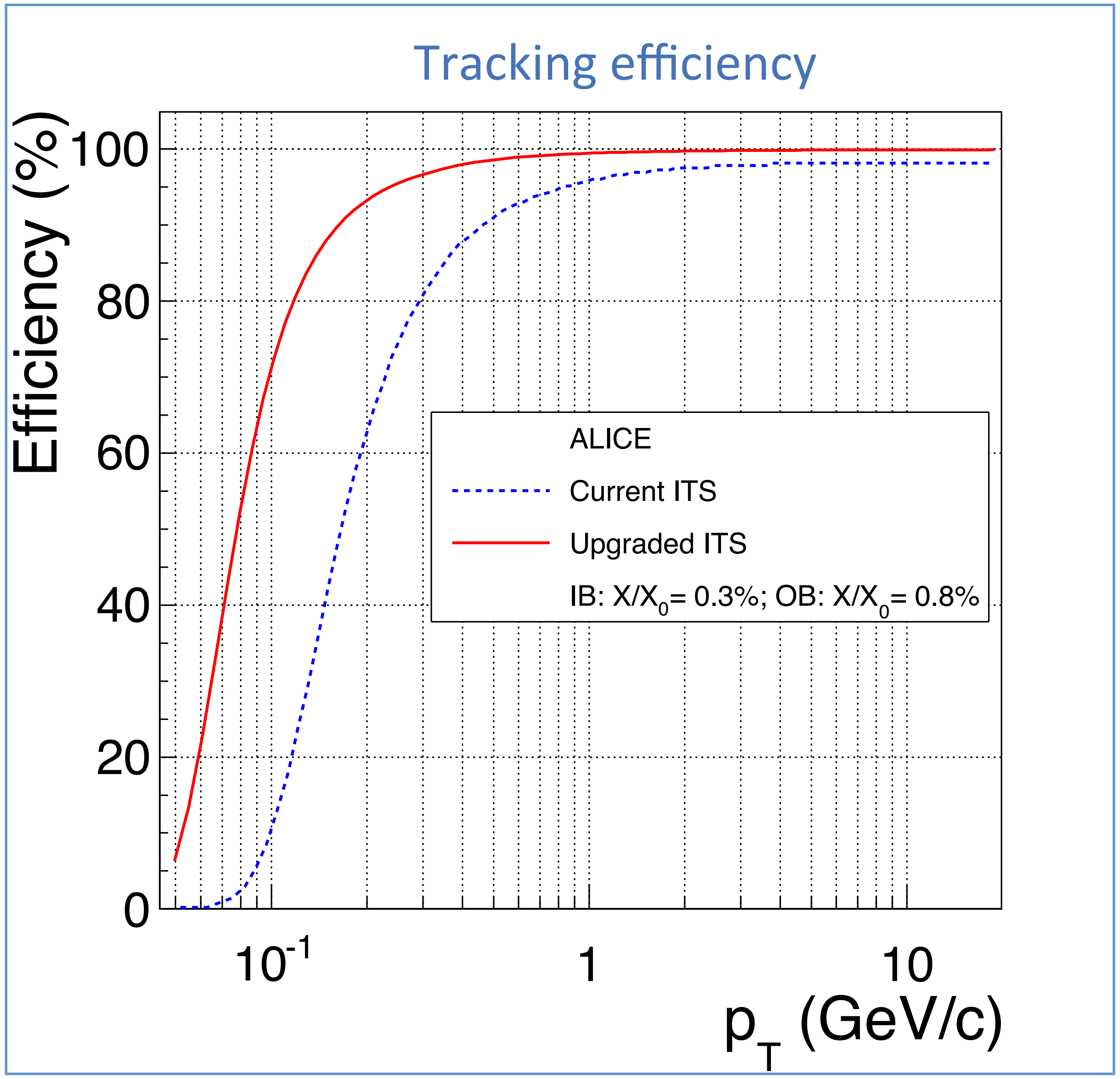
many slides borrowed with credit to L. Musa

ITS Motivation

Impact parameter resolution



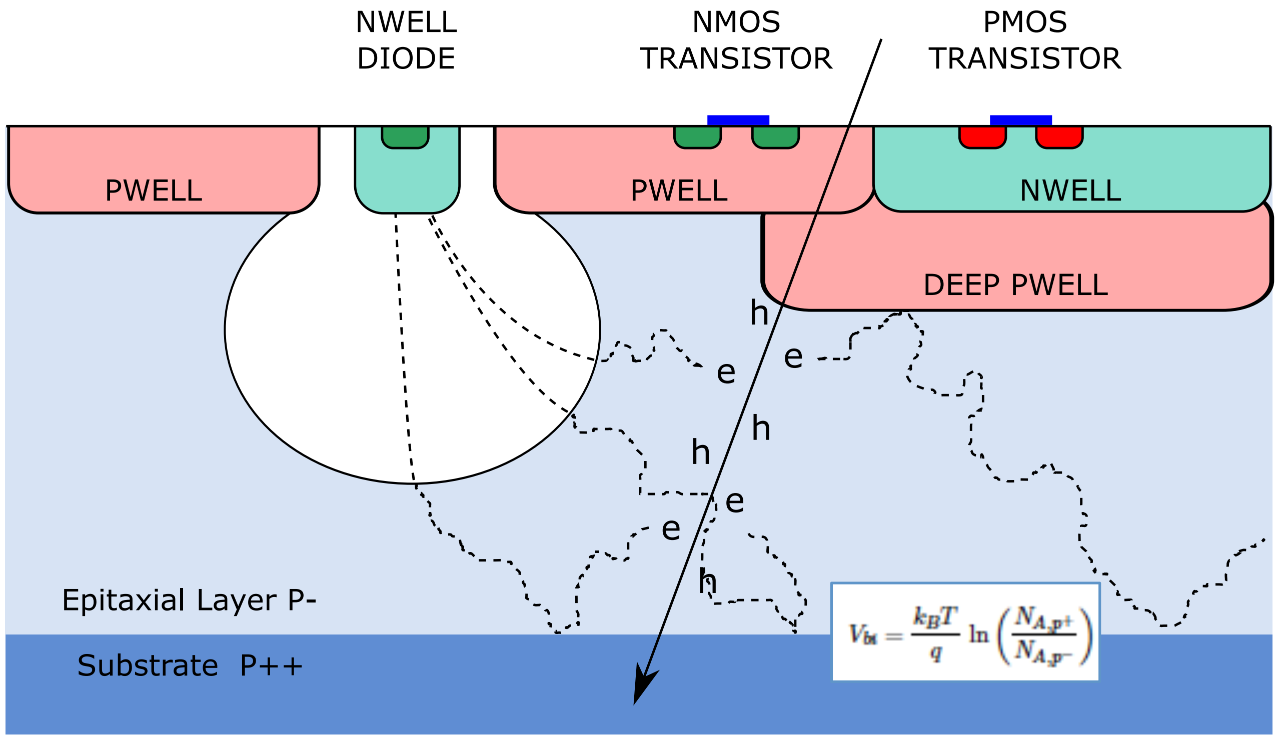
Tracking efficiency (ITS standalone)



~40 μm at p_T = 500 MeV/c

ALPIDE pixel technology

CMOS Pixel Sensor using TowerJazz 0.18μm CMOS Imaging Process



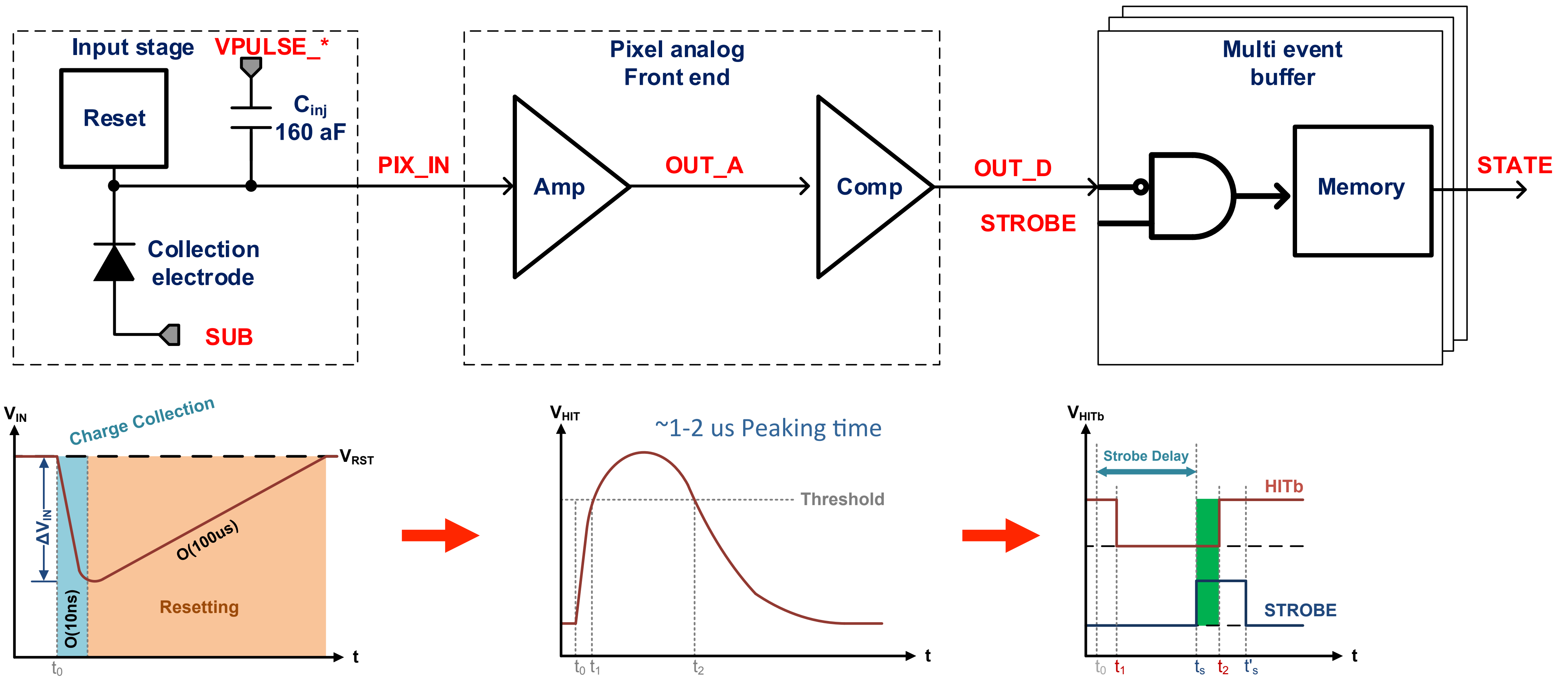
Tower Jazz 0.18 μm CMOS

- feature size 180 nm
- metal layers 6
- gate oxide 3nm

substrate:	$N_A \sim 10^{18}$
epitaxial layer:	$N_A \sim 10^{13}$
deep p-well:	$N_A \sim 10^{16}$

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (18μm to 30μm) on p-type substrate
- Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance
- Application of (moderate) reverse bias voltage to substrate (contact from the top) can be used to increase depletion zone around NWELL collection diode
- Deep PWELL shields NWELL of PMOS transistors to allow for full CMOS circuitry within active area

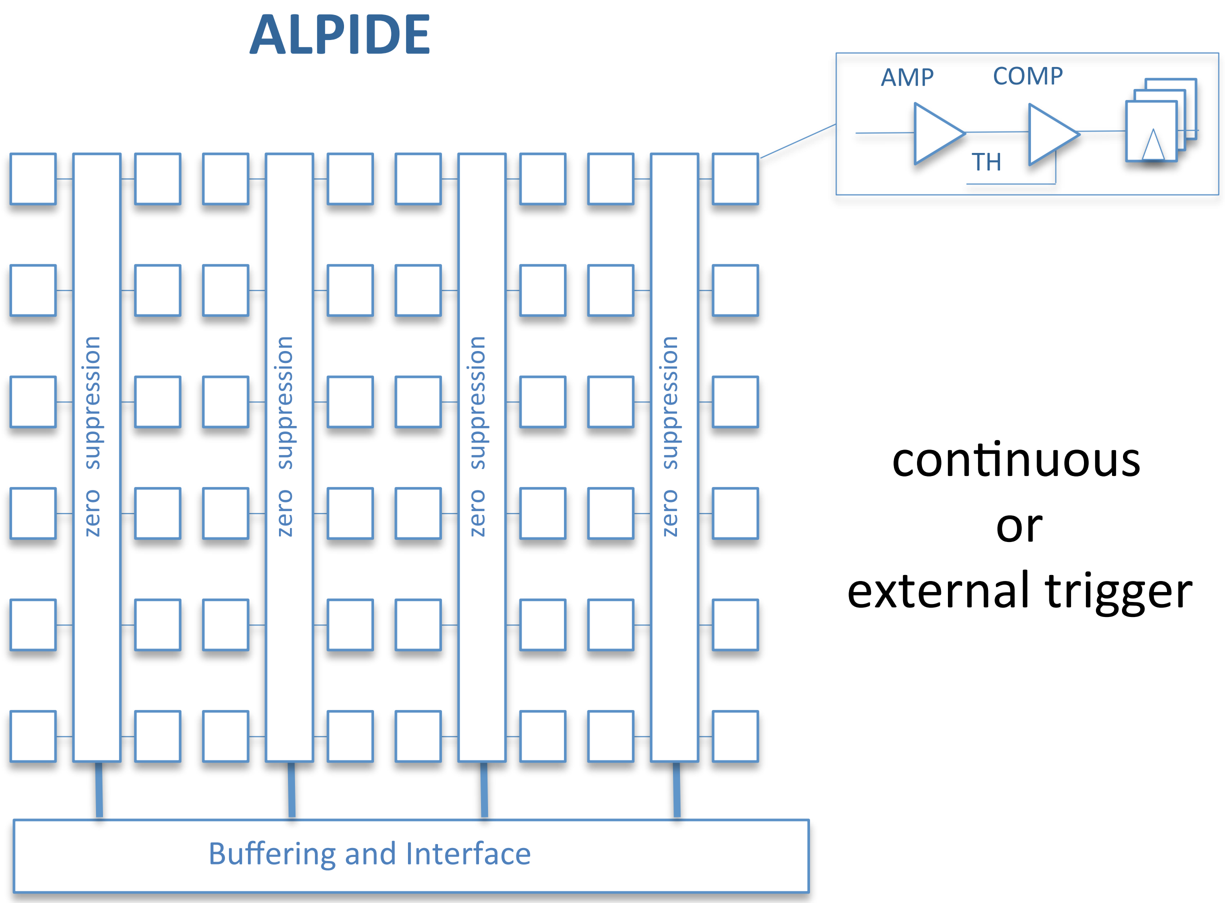
ALPIDE Operation



Front-end acts as delay line

- Sensor and front-end continuously active
- Upon particle hit front-end forms a pulse with ~1-2μs peaking time
- Threshold is applied to form binary pulse
- Hit is latched into a (3-bit) memory if strobe is applied during binary pulse

ALPIDE Readout



continuous
or
external trigger

Architecture

- In-pixel amplification
- In-pixel discrimination
- In-pixel (multi-) hit buffer
- In-matrix sparsification

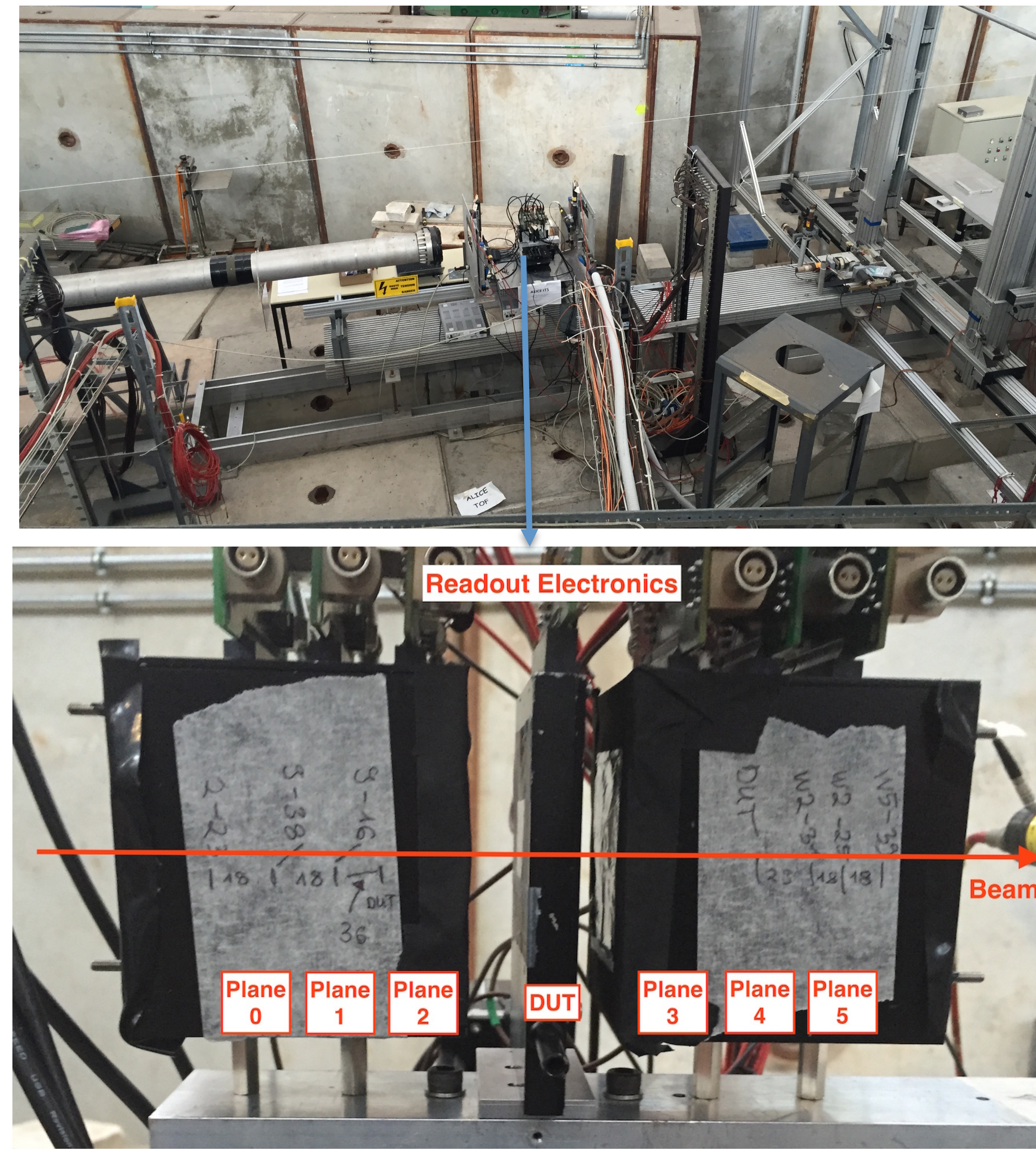
Key Features

- 28 μm x 28 mm pixel pitch
- Continuously active, ultra-low power front-end (40nW/pixel)
- No clock propagation to the matrix ➔ ultra-low power matrix readout (2mW whole chip)
- Global shutter (<10μs): triggered acquisition or continuous

CERN Test Beam

Test Beam Set-up

- 6 GeV/c π^- beam at CERN PS
- 6 reference planes based on pALPIDE-1
- Single pALPIDE-2 as Device Under Test (DUT) in the center
- Track resolution of about 2.8μm (<< 28μm)



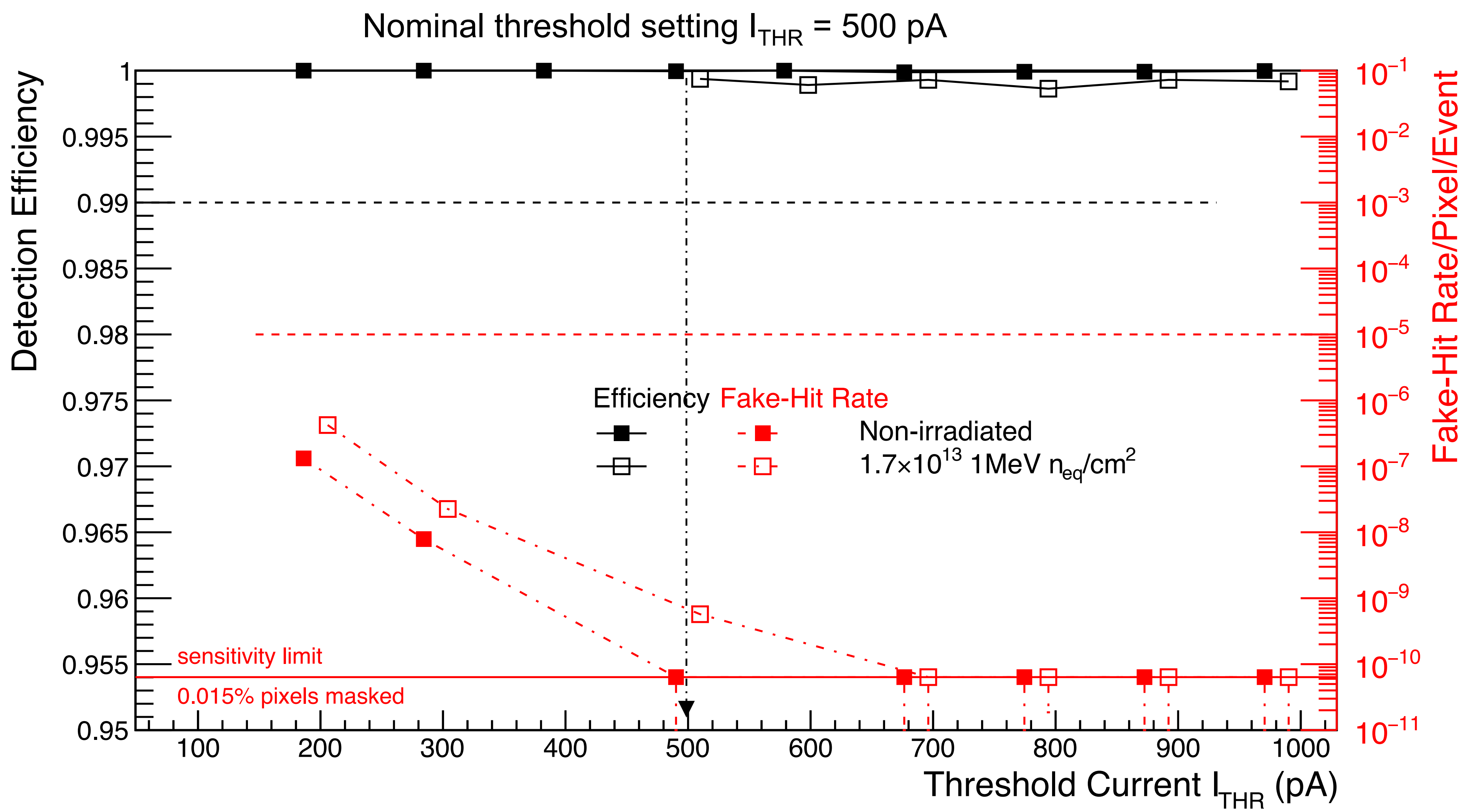
Analysis Method

- Extrapolate track from referecne planes trough DUT
- Search for clusters next to extrapolated impinging point → detection efficiency
- Obtain **cluster size**
- Compare extrapolated and actual position → **position resolution**

ALICE Test Beam Data

Efficiency and fake hit rate

epi=30μm, V_{BB}=-6V, spacing=4μm



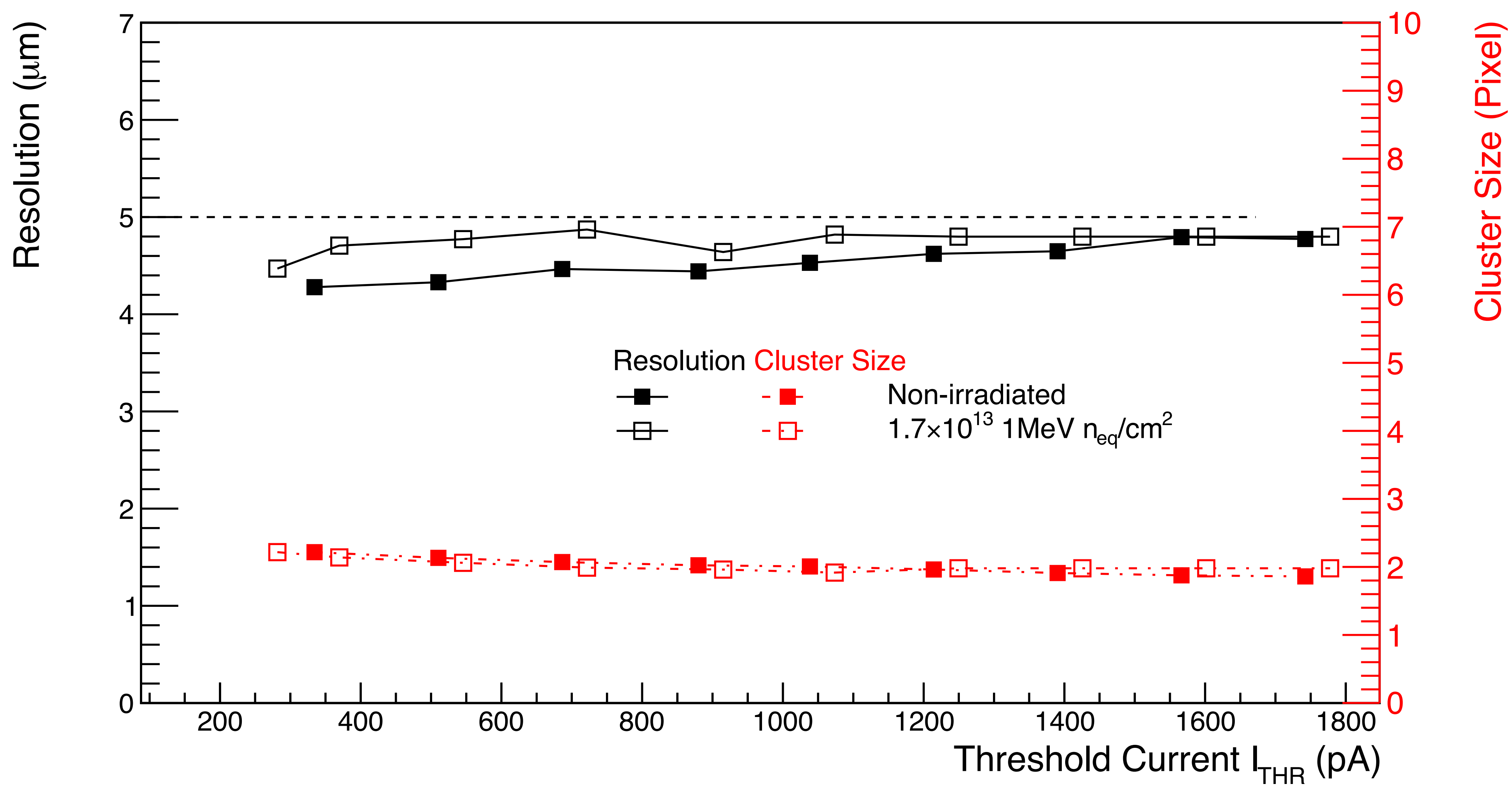
Even larger operation margin for 30μm epi layer and 4μm spacing

- Results refer to chips with 30μm high-res epi layer, thinned to 50 μm: 1 non irradiated and 1 irradiated with 10^{13} 1MeV n_{eq} / cm^2

ALICE Test Beam Data #2

Spatial Resolution and Cluster Size

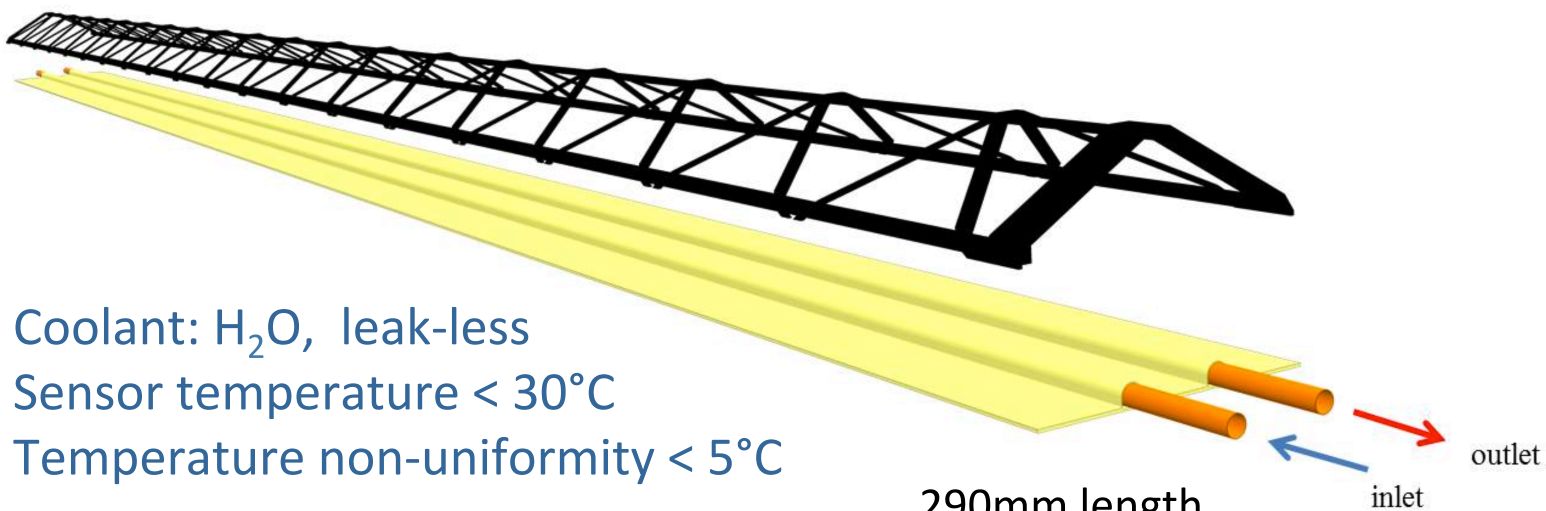
epi=30μm, V_{BB}=-6V, spacing=4μm



σ_{det} ≈ 5 μm is achieved before and after irradiation

- Results refer to chips with 30μm high-res epi layer, thinned to 50 μm
  1 non irradiated and 1 irradiated with $1.7x10^{13}$ 1MeV n_{eq} / cm^2

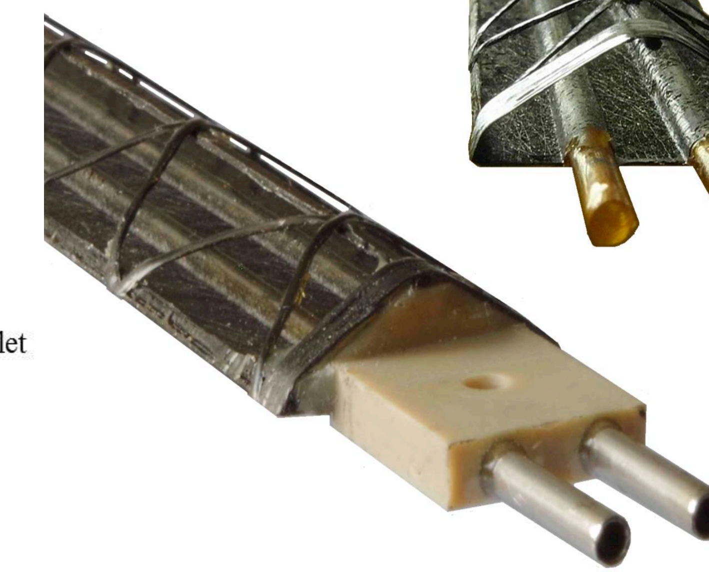
Inner Barrel Staves



Coolant: H_2O, leak-less
Sensor temperature < 30°C
Temperature non-uniformity < 5°C

290mm length

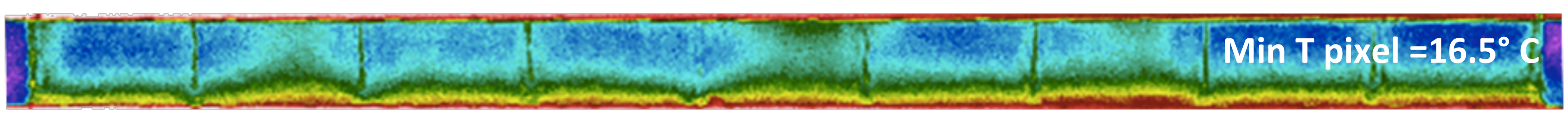
1.5gram weight



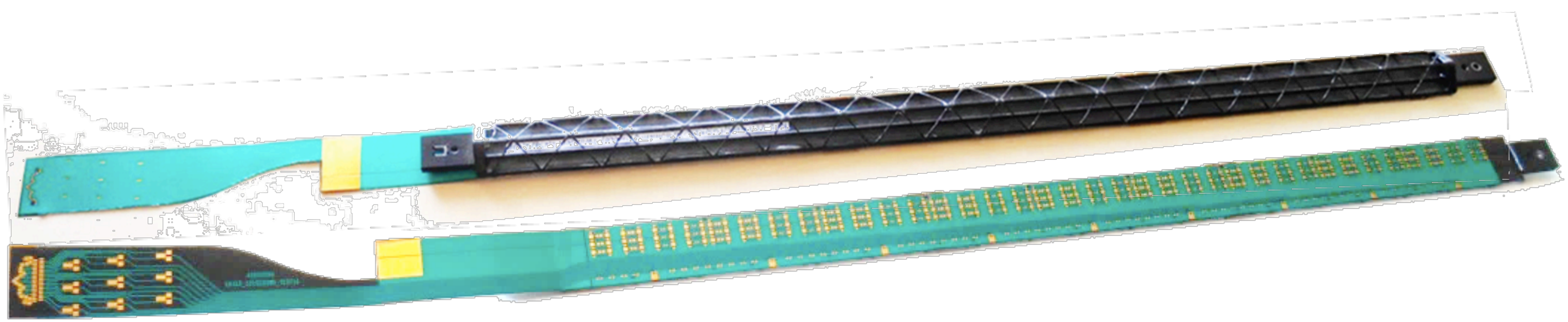
W = 100 mW / cm^2 (> x2 nominal) , H_2O flow rate = 3 Lh^{-1}

Tin=15.8° C

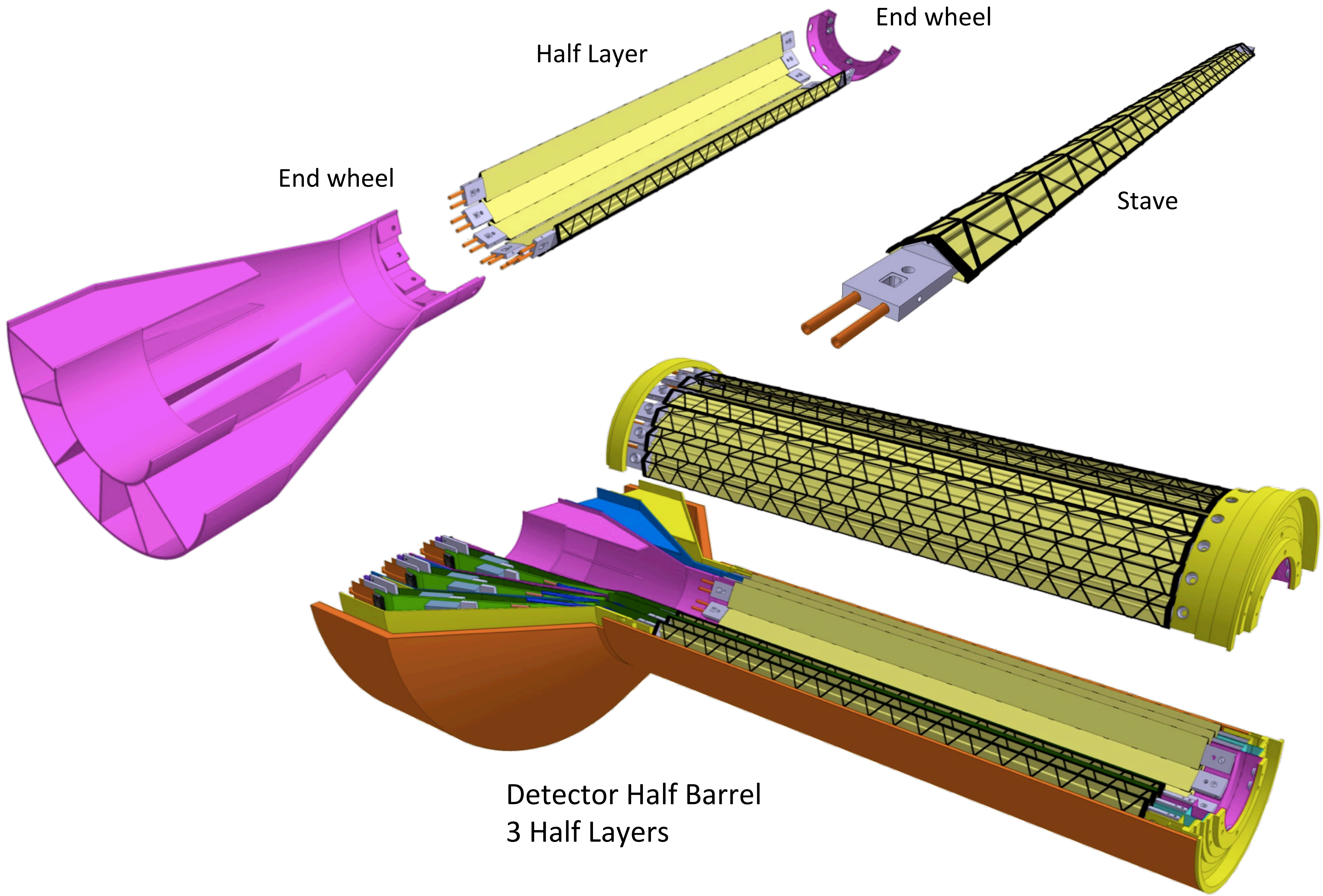
Tout=16.6 °C



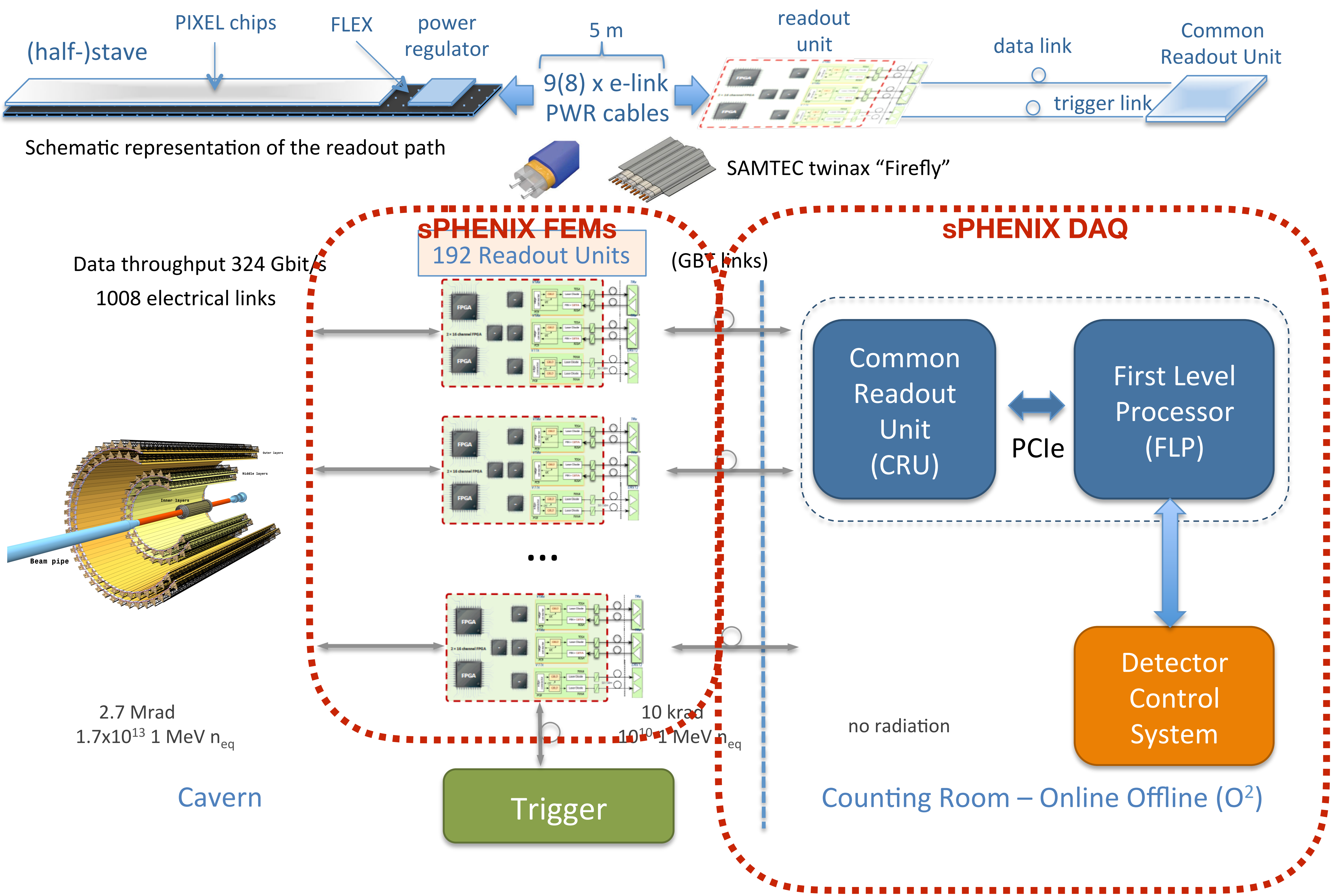
Max T periph=18.5° C



ALICE Inner Barrel Support & Services



Readout Scheme



MAPS Cost & Schedule Workfest

https://indico.bnl.gov/conferenceDisplay.py?confId=1741

sPHENIX MAPS Cost & Schedule Workfest

from 30 March 2016 to 01 April 2016 (US/Mountain) *El Dorado Hotel*
US/Mountain timezone

Search

Overview
Timetable
Contribution List
Author index
Registration
Registration Form
List of registrants

Organizers

The purpose of this 3 day workfest is to define and document the cost and schedule for the MAPS based tracking options under consideration for the sPHENIX detector. The interactive workfest format will be organized into topical breakout teams with MAPS, engineering, and C&S experts we are gathering from ALICE, sPHENIX, and other projects and will minimize time spent in presentations.

Update 3/2/16: The workfest will be held at the El Dorado Hotel. The hotel is located just a short walk west of the historic downtown square. See http://www.eldoradohotel.com for more hotel details. We've arranged for a block of rooms is available now and can be booked at the workfest/gov't rate ($99/night) if you follow: https://gc.synxis.com/rez.aspx?Hotel=63150&Chain=17123&Dest=Santa Fe &template=GCF&shell=GCF&locale=en-US&arrive=3/29/2016&depart=4/1/2016&adult=1&child=0&group=sPHENIX which will lead you to a web form for the conference. If you decide to call the hotel directly at 505-995-4500, our call-in/group code for the reservations is: sPHENIX.

FAQ: *Should I fly out of ABQ on Friday evening or Saturday morning?*

The answer to this is if you can find a suitable flight or not. We expect that some participants will book flights out Friday evening and leave the workfest in the afternoon to take those flights. Not all participants will find a flight and so Saturday morning will be an option for them. Our plan is to be finalizing the C&S document on Friday afternoon. The organizers will stay until the end of the day and go to dinner with the remaining participants. The drive from Santa Fe to the airport (ABQ) will take approximately 1 hour.

Dates: from 30 March 2016 09:00 to 01 April 2016 17:30
Timezone: US/Mountain

MAPS Cost & Schedule Workfest

sPHENIX MAPS Cost & Schedule Workf

is located just a
hotel.com for more
be booked at the

ill lead you to a
995-4500, our

some participants
to take those
an option for
he organizers will
nts. The drive from

Location: *El Dorado Hotel*
309 W San Franscisco St.

Participants

Current registrants (17)

name	institution	position	city	country/region
Prof. FIELDS, Douglas	University of New Mexico	Professor	Albuquerque	UNITED STATES OF AMERICA
FRAWLEY, Anthony	Florida State University		Tallahassee	UNITED STATES OF AMERICA
GREINER, leo	LBNL		Berkeley	UNITED STATES OF AMERICA
Dr. HUANG, Jin	Brookhaven National Lab		Upton	UNITED STATES OF AMERICA
Dr. LIM, Sanghoon	LANL	post-doc	Los ALAMOS	UNITED STATES OF AMERICA
Dr. LIU, Ming	Los Alamos		Los Alamos	UNITED STATES OF AMERICA
Dr. LI, Xuan	LANL		Los Alamos	UNITED STATES OF AMERICA
Dr. MCCUMBER, Michael	Los Alamos National Laboratory		Los Alamos, NM	UNITED STATES OF AMERICA
MCGLINCHEY, Darren	University of Colorado Boulder	Postdoc	Boulder	UNITED STATES OF AMERICA
Dr. O'BRIEN, Edward	Brookhaven National Lab		Upton, NY	UNITED STATES OF AMERICA
Prof. OKOROKOV, Vitalii	National Research Nuclear University MEPhI	Professor	Moscow	RUSSIA
Dr. PEREPELITSA, Dennis	Brookhaven National Laboratory (US)	Goldhaber Fellow	New York	UNITED STATES OF AMERICA
Prof. REDWINE, Robert	MIT	Director, Bates Laboratory	Cambridge, MA	UNITED STATES OF AMERICA
Prof. ROLAND, Gunther	MIT		Cambridge	GERMANY
SICHTERMANN, Ernst	Lawrence Berkeley National Laboratory		Berkeley	UNITED STATES OF AMERICA
Mr. SONDHEIM, Walter	LANL		Los Alamos	UNITED STATES OF AMERICA
Dr. VIDEBAEK, Flemming	Brookhaven National Laboratory		Upton, NY11973	UNITED STATES OF AMERICA

Good turnout
20 people attend in-person
most listed here as registrants

Key Invited Experts:
Leo Greiner, LBL
Flemming Videbaek, BNL
Luciano Musa, CERN (phone)

Participants

Curren

name
Prof. FIELD
FRAWLEY, A
GREINER, I
Dr. HUANG,
Dr. LIM, Sa
Dr. LIU, Mir
Dr. LI, Xuar
Dr. MCCUM
MCGLINCHI
Dr. O'BRIEN
Prof. OKOR
Dr. PEREPE
Prof. REDW
Prof. ROLAI
SICHTERMA
Mr. SONDH
Dr. VIDEBA

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Presentations

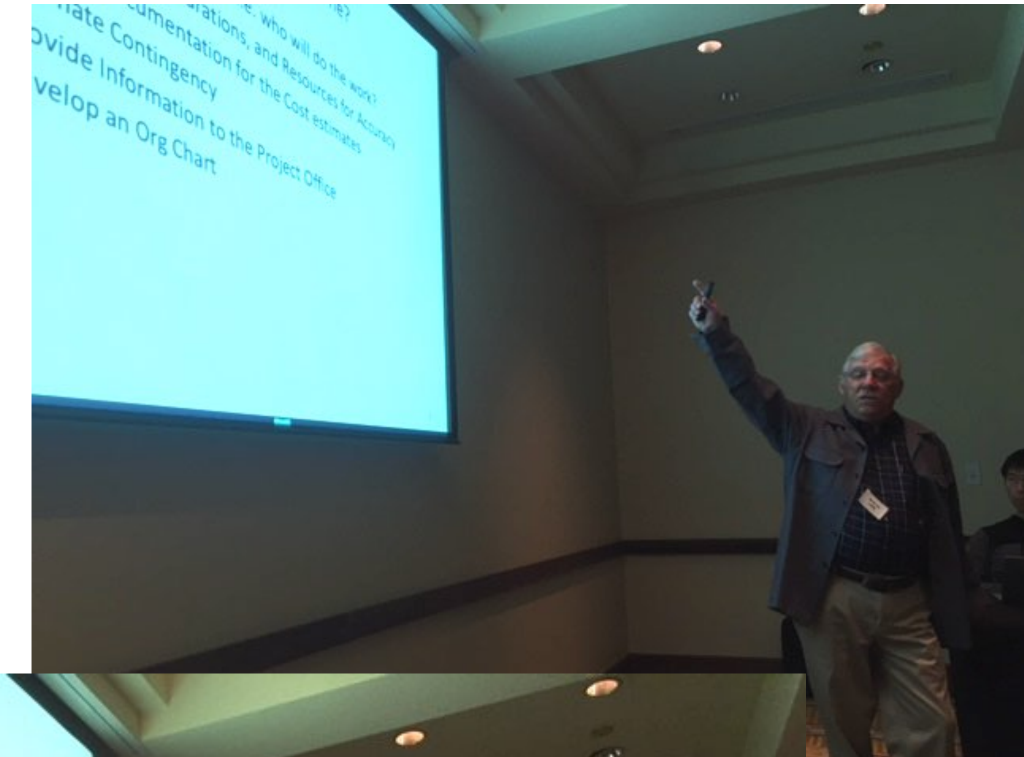
1st Day

09:05 **MAPS in sPHENIX** *20'*
Speaker: Prof. Tony Frawley (FSU)
Material: Slides

09:25 **Draft Cost & Schedule Document and Project File** *20'*
Speaker: Dr. David Lee (LANL)
Material: Slides

09:45 **HFT Project Management Perspective** *45'*
Speaker: Dr. Flemming Videbaek (BNL)
Material: Slides

10:30 **MAPS Readout Experience** *45'*
Speaker: Dr. Leo Greiner (LBL)
Material: Slides



2nd Day

10:00 **ALICE ITS Overview & Discussion** *2h0'*
Speaker: Dr. Luciano Musa (CERN)
Material: Slides

Work Sessions

Suggested Membership:

Gold Team: Project Experts
WBS 1.4,1.9, FTE & Budget Summaries
1. Executive Overview
8. Management

Ed O'Brien
Flemming Videbaek

Green Team: Detector Hardware Experts
WBS 1.5,1.6,1.7,1.10.1-8,1.11
4. MAPS Sensors
5. Readout Electronics

Leo Greiner

Red Team: Engineering Experts
WBS 1.8,1.12,1.10.9-12,1.12
6. Mechanics and Servicing
7. Installation

Walter Sondheim
Hubert Van Hecke

Blue Team: Science and Simulation Experts
Tracking Code Development / sPHENIX tutorials
2. Scientific Impact
3. Tracking Overview

Tony Frawley

Work Sessions

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8. Manage

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Red Team:

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Blue Team:

Tracking

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Red Team
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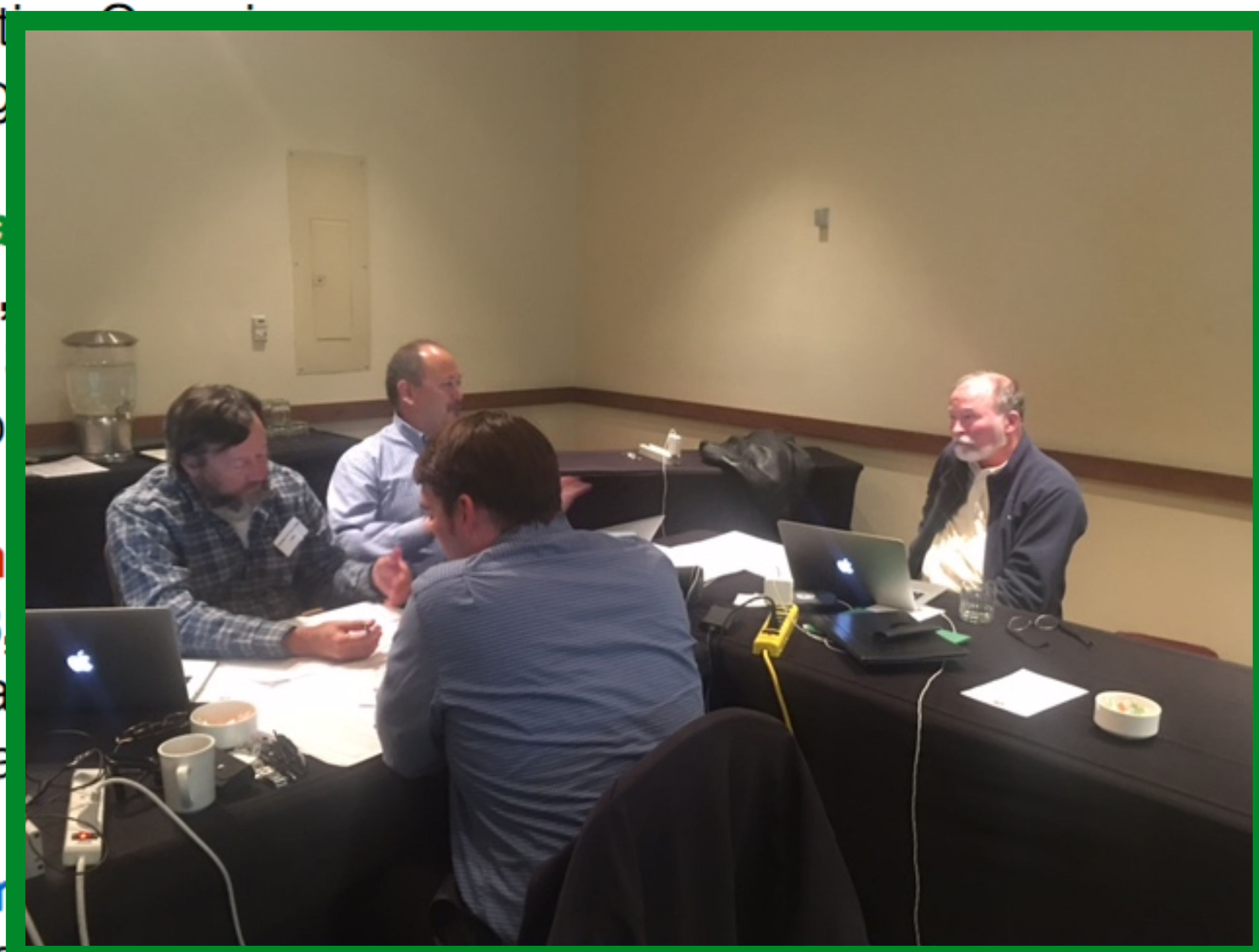
Blue Team
Tracking
2. Scientific Impact
3. Tracking Overview

Tony Frawley



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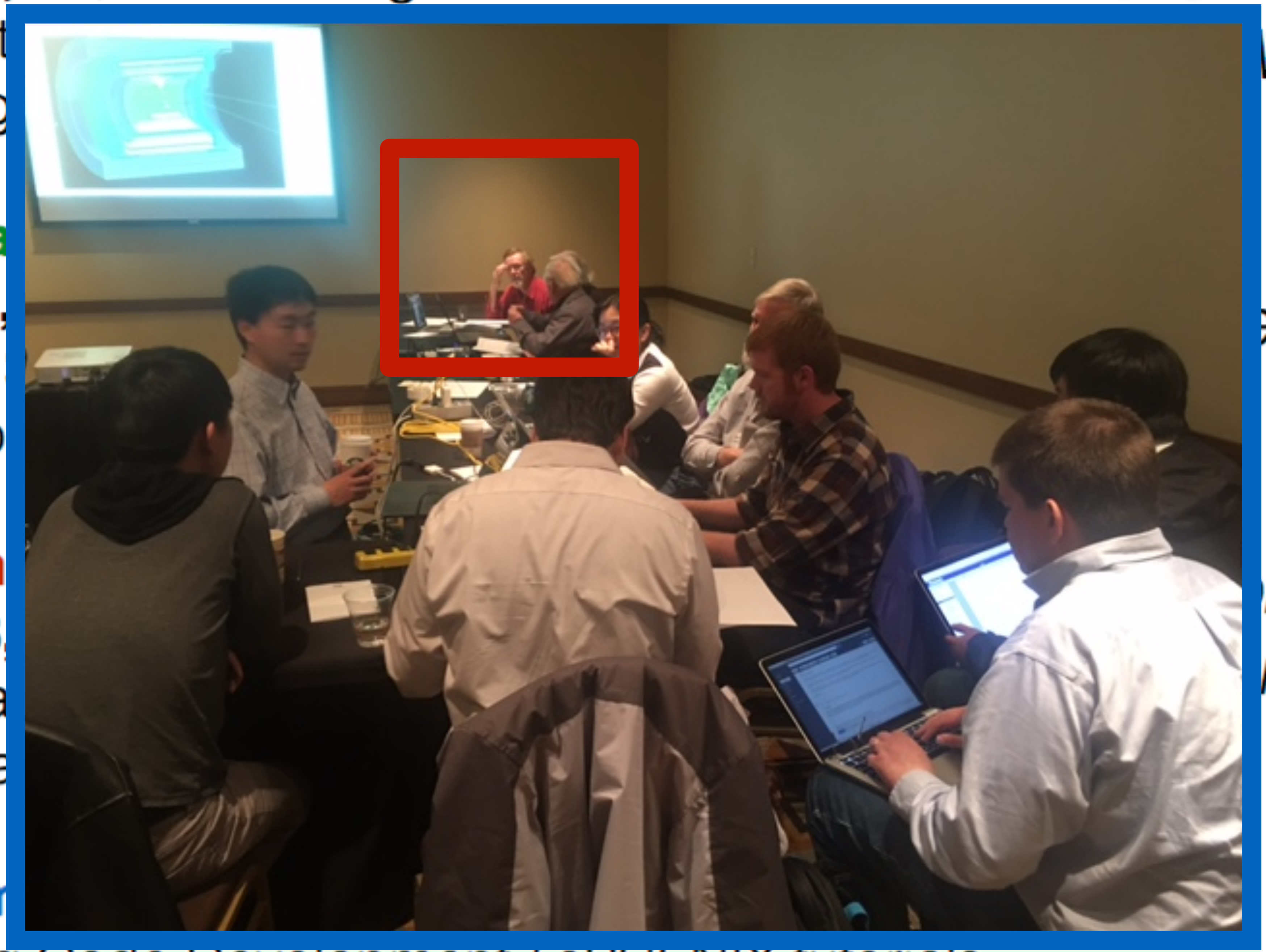


Blue Team

Tracking Code Development / sPHENIX tutorials

2. Scientific Impact

3. Tracking Overview

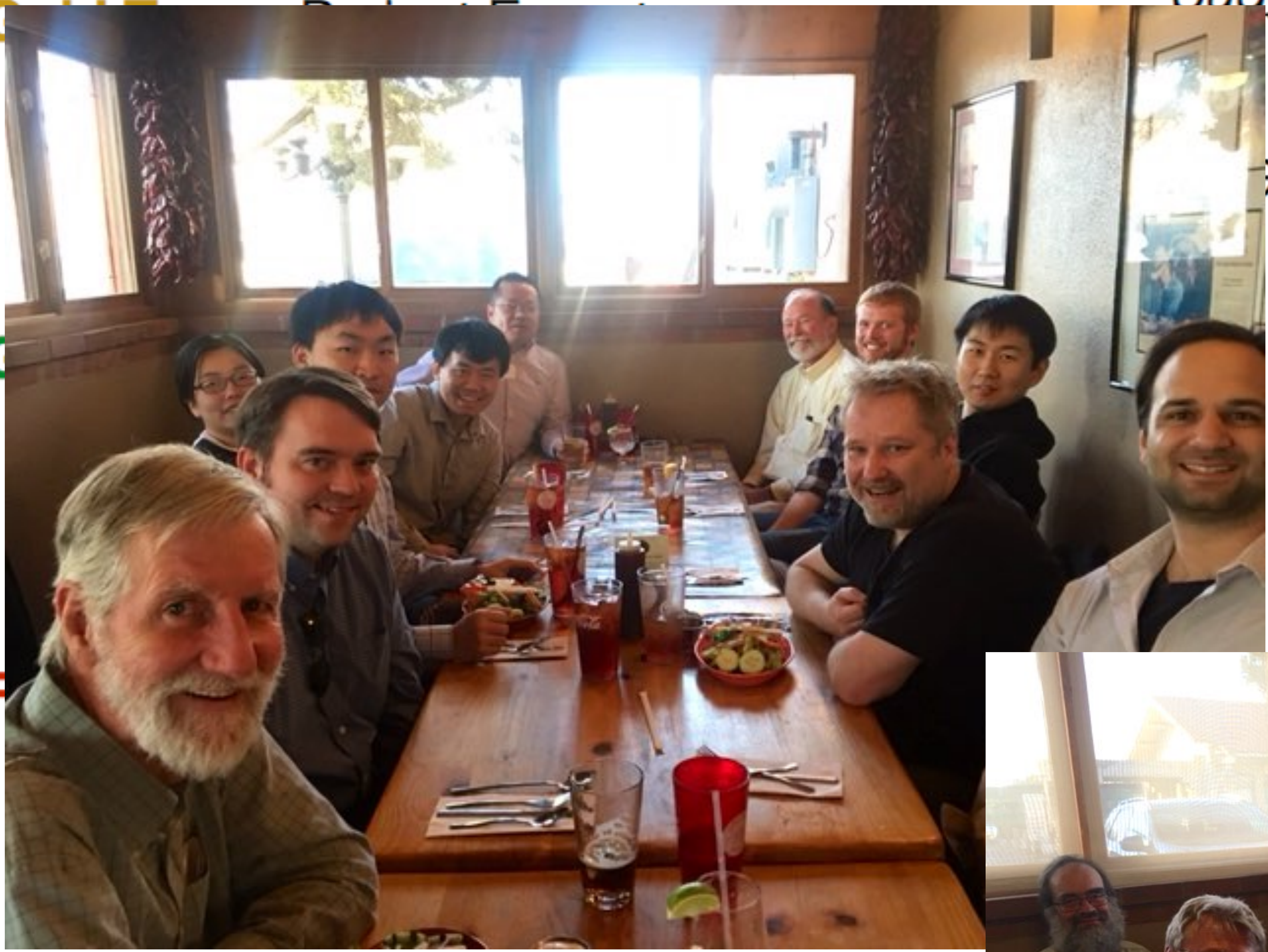
Tony Frawley

Work Sessions

Suggested Membership:

Ed O'Brien

emming Videbaek



Leo Greiner

Blue Team: Science and Simulation Exp

Tracking Code Development / sPHEN

2. Scientific Impact
3. Tracking Overview

Aside: ALICE Wire Bonding

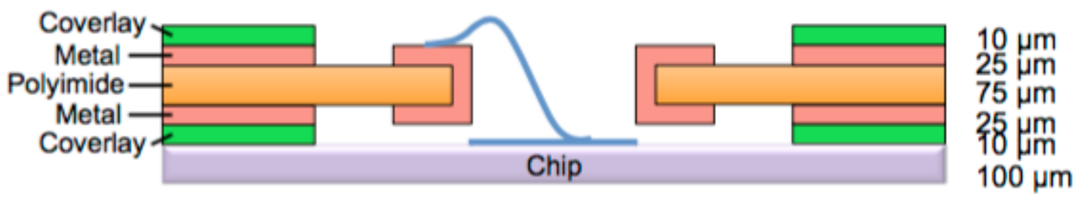
digital pathways will be wire bonded…

Interconnection of pixel chip to flex PCB

A Large Ion Collider Experiment

ALICE

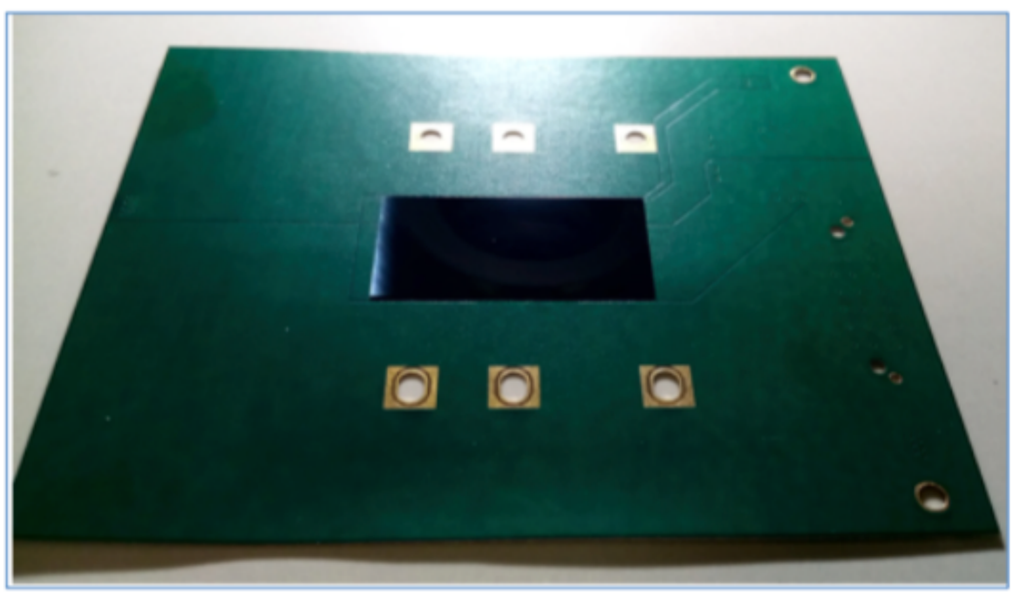
Wire bonding



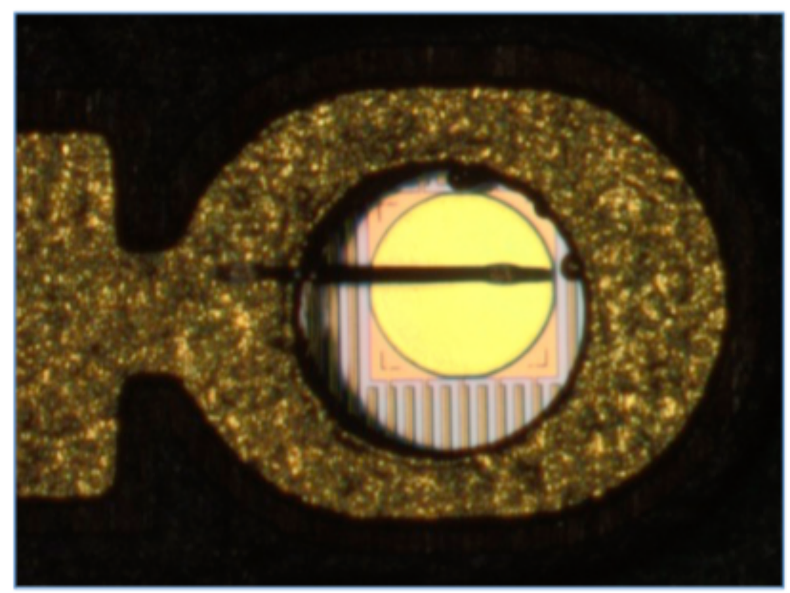
Tests with pALPIDE-3 single-chip HIC

- 5 with 25µm Al wire and standard wedge tool
- 1 with 25µm Al wire and deep access wedge tool
- **Results: all working according to specs**

First tests done in January with single-chip assemblies



Chip glued on the FPC

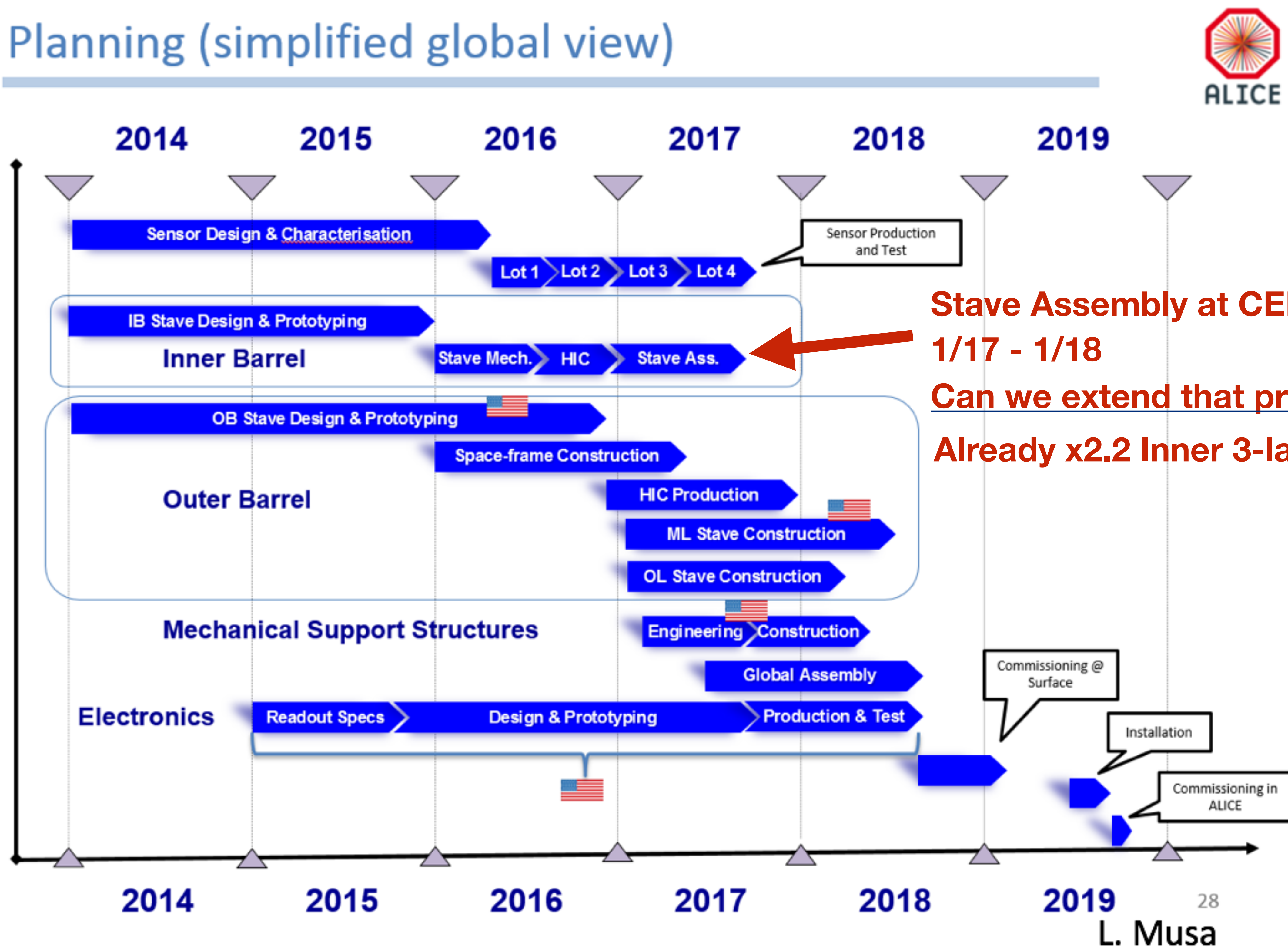


Wire Bonding

ALICE Construction Schedule

Current Schedule + *add ~6 months*

Planning (simplified global view)



Stave Assembly at CERN 1/17 - 1/18

Can we extend that production?

Already x2.2 Inner 3-layers

Draft Cost & Schedule Document

1	**1**	**sPIT Project**	**1054 days**	**Mon 10/3/16**	**Thu 10/15/20**	**$3,061,898.18**
2	1.1	Start Construction (CD-3)	1 day	Mon 11/13/17	Mon 11/13/17	$0.00
3	1.2	ALICE Inner Barrel Construction	261 days	Mon 1/2/17	Mon 1/1/18	$0.00
4	1.3	Start R&D LANL	1 day	Mon 10/3/16	Mon 10/3/16	$0.00
5	1.4	Start R&D Other Institutions	1 day	Mon 10/3/16	Mon 10/3/16	$0.00
6	**1.5**	**Project Management**	**815 days**	**Fri 10/14/16**	**Fri 11/29/19**	**$147,200.00**
7	1.5.1	Project Manager	800 days	Fri 10/14/16	Fri 11/8/19	$0.00
8	1.5.2	Mechanical Liason Engineer	800 days	Fri 11/4/16	Fri 11/29/19	$73,600.00
9	1.5.3	Electronics Liason Engineer	800 days	Fri 11/4/16	Fri 11/29/19	$73,600.00
10	**1.6**	**Design & Prototyping**	**276 days**	**Mon 10/3/16**	**Mon 10/23/17**	**$669,818.18**
11	**1.6.1**	**Readout Test Stand**	**26 days**	**Mon 10/3/16**	**Mon 11/7/16**	**$34,800.00**
15	**1.6.2**	**Staves**	**45 days**	**Mon 2/27/17**	**Fri 4/28/17**	**$61,400.00**
18	**1.6.3**	**Readout Electronics**	**223 days**	**Mon 10/3/16**	**Wed 8/9/17**	**$130,018.18**
35	**1.6.4**	**Ancillary**	**60 days**	**Tue 10/18/16**	**Mon 1/9/17**	**$56,200.00**
39	**1.6.5**	**Mechanics**	**276 days**	**Mon 10/3/16**	**Mon 10/23/17**	**$387,400.00**
65	**1.7**	**Prototype Assembly**	**40 days**	**Thu 3/9/17**	**Wed 5/3/17**	**$20,800.00**
69	1.8	Test Beam Operation	3 wks	Thu 10/5/17	Wed 10/25/17	$0.00
70	**1.9**	**sPIT-DOE Final Review**	**14 days**	**Tue 10/24/17**	**Fri 11/10/17**	**$52,000.00**
74	**1.10**	**Procurements**	**519 days**	**Mon 11/13/17**	**Thu 11/7/19**	**$2,008,480.00**
75	1.10.1	Procure 58 Inner Staves	120 days	Mon 1/1/18	Fri 6/15/18	$823,400.00
76	1.10.2	Procure 100 SamTec Cables	2 mons	Mon 11/13/17	Fri 1/5/18	$39,800.00
77	1.10.3	Procure 58 Readout Units	2 mons	Mon 1/8/18	Fri 3/2/18	$287,800.00
78	1.10.4	Procure Optical Links	2 mons	Mon 3/5/18	Fri 4/27/18	$48,800.00
79	1.10.5	Procure 29 Common Readout Units	2 mons	Mon 4/30/18	Fri 6/22/18	$167,800.00
80	1.10.6	Procure Ancillary Materials	2 mons	Mon 6/25/18	Fri 8/17/18	$72,800.00
81	1.10.7	Procure Cooling Plant	2 mons	Mon 8/20/18	Fri 10/12/18	$129,800.00
82	1.10.8	Procure assembly fixtures & jigs	60 days	Mon 10/15/18	Fri 1/4/19	$119,200.00
83	1.10.9	Procure end wheels	64 days	Mon 1/7/19	Thu 4/4/19	$54,480.00
84	1.10.10	Procure Cylindrical structural Shells	14 days	Fri 4/5/19	Wed 4/24/19	$15,480.00
85	1.10.11	Procure Detector Half Barrels	14 days	Thu 4/25/19	Tue 5/14/19	$17,480.00
86	1.10.12	Procure Service Half Barrels	32 days	Wed 5/15/19	Thu 6/27/19	$130,240.00
87	1.10.13	Procure Detector and Service Half Barrels	15 days	Fri 6/28/19	Thu 7/18/19	$25,800.00
88	1.10.14	Procure Two Half Support Structures	4 mons	Fri 7/19/19	Thu 11/7/19	$75,600.00
89	**1.11**	**Assembly and Testing**	**205 days**	**Fri 11/8/19**	**Thu 8/20/20**	**$99,600.00**
96	1.12	Installation	2 mons	Fri 8/21/20	Thu 10/15/20	$64,000.00

Draft Cost & Schedule Document

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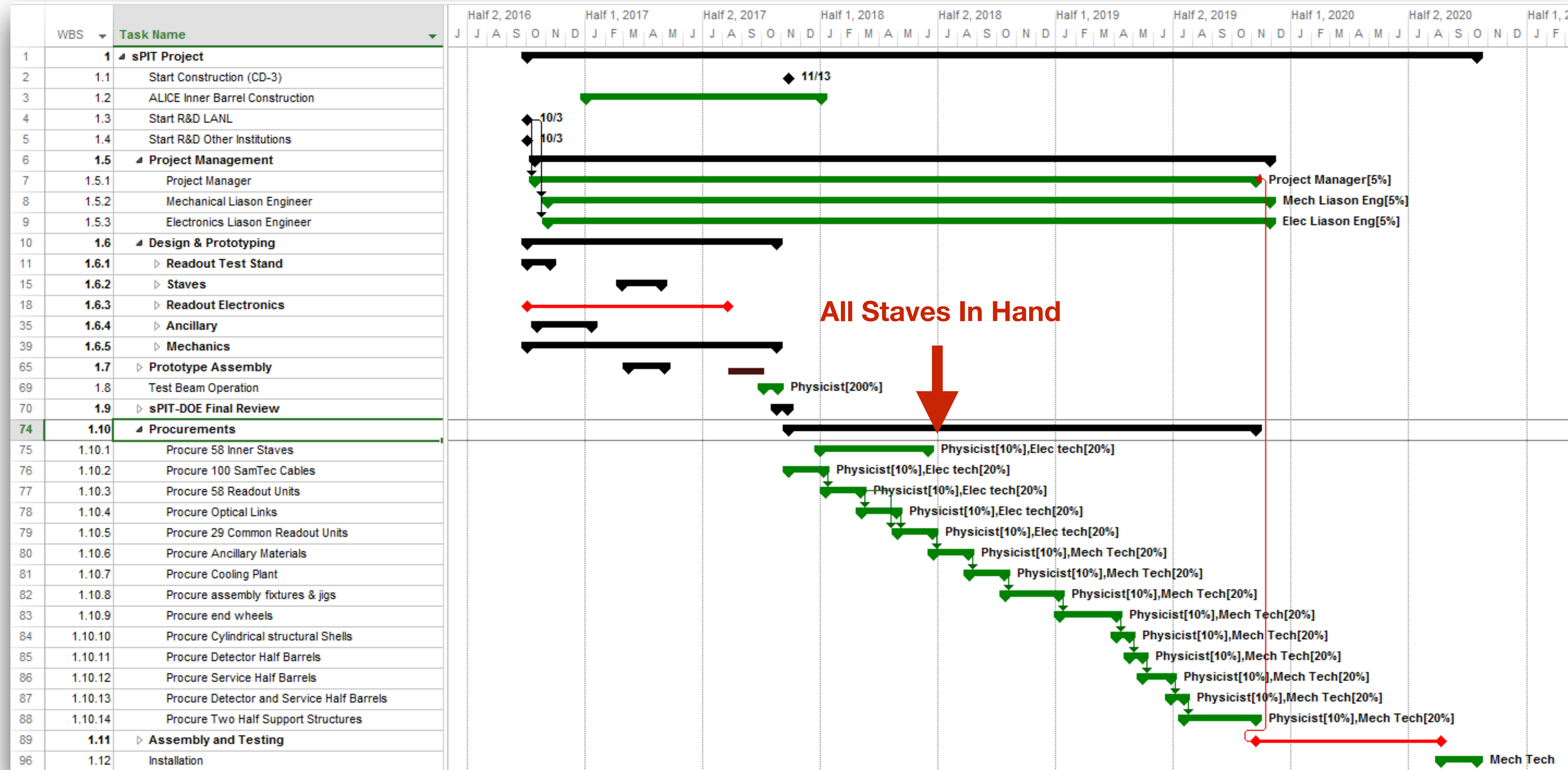
96	1.12	Installation	2 mons	Fri 8/21/20	Thu 10/15/20	$64,000.00

~$3-4M

~$2-3M

But Will Require Further Updates



Parallelize procurements (detector hardware, mechanics & servicing)

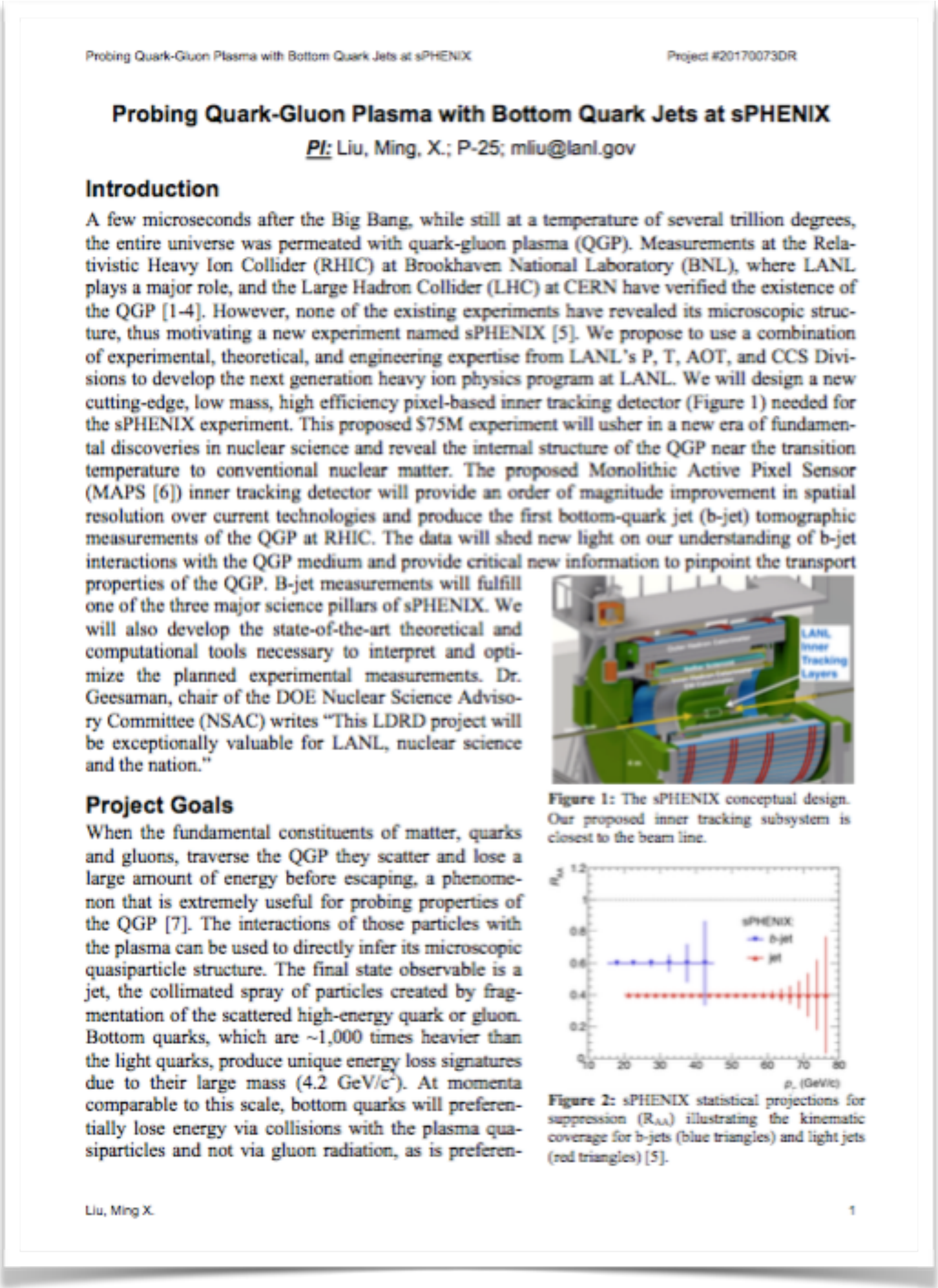
Add more time for R&D on readout

Contingency for custom readout boards (~$750k)

Finish loading document (will have to happen after DR proposal)

Will be have to be done by Tracking Review

LANL LDRD Proposal



Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX Project #20170073DR

Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX

PI: Liu, Ming, X.; P-25; mliu@lanl.gov

Introduction

A few microseconds after the Big Bang, while still at a temperature of several trillion degrees, the entire universe was permeated with quark-gluon plasma (QGP). Measurements at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), where LANL plays a major role, and the Large Hadron Collider (LHC) at CERN have verified the existence of the QGP [1-4]. However, none of the existing experiments have revealed its microscopic structure, thus motivating a new experiment named sPHENIX [5]. We propose to use a combination of experimental, theoretical, and engineering expertise from LANL's P, T, AOT, and CCS Divisions to develop the next generation heavy ion physics program at LANL. We will design a new cutting-edge, low mass, high efficiency pixel-based inner tracking detector (Figure 1) needed for the sPHENIX experiment. This proposed $75M experiment will usher in a new era of fundamental discoveries in nuclear science and reveal the internal structure of the QGP near the transition temperature to conventional nuclear matter. The proposed Monolithic Active Pixel Sensor (MAPS [6]) inner tracking detector will provide an order of magnitude improvement in spatial resolution over current technologies and produce the first bottom-quark jet (b-jet) tomographic measurements of the QGP at RHIC. The data will shed new light on our understanding of b-jet interactions with the QGP medium and provide critical new information to pinpoint the transport properties of the QGP. B-jet measurements will fulfill one of the three major science pillars of sPHENIX. We will also develop the state-of-the-art theoretical and computational tools necessary to interpret and optimize the planned experimental measurements. Dr. Geesaman, chair of the DOE Nuclear Science Advisory Committee (NSAC) writes "This LDRD project will be exceptionally valuable for LANL, nuclear science and the nation."

Figure 1: The sPHENIX conceptual design. Our proposed inner tracking subsystem is closest to the beam line.

Project Goals

When the fundamental constituents of matter, quarks and gluons, traverse the QGP they scatter and lose a large amount of energy before escaping, a phenomenon that is extremely useful for probing properties of the QGP [7]. The interactions of those particles with the plasma can be used to directly infer its microscopic quasiparticle structure. The final state observable is a jet, the collimated spray of particles created by fragmentation of the scattered high-energy quark or gluon. Bottom quarks, which are ~1,000 times heavier than the light quarks, produce unique energy loss signatures due to their large mass (4.2 GeV/c^2). At momenta comparable to this scale, bottom quarks will preferentially lose energy via collisions with the plasma quasiparticles and not via gluon radiation, as is preferen-

Figure 2: sPHENIX statistical projections for suppression (R_{AA}) illustrating the kinematic coverage for b-jets (blue triangles) and light jets (red triangles) [5].

Liu, Ming X. 1

Funding Profile:
$5M spread over 3 years starting in Oct 2016

Funding Breakdown:
~1/3 M&S
~1/3 Experiment Staffing
~1/3 Theory Staffing

Proposals judged on many factors, coverage from multiple divisions, strong Theory is necessary to success

M&S total: $1.5M

Total Experimental Support: $3M

We submitted our proposal last Thursday (May 12) . We will defend it on June 2nd. I expect decision by mid-July.

Strong Letters of Support

The sPHENIX Experiment at RHIC

Dr. Dave Morrison
sPHENIX Co-Spokesperson
Brookhaven National Laboratory
Upton, NY 11973

Prof. Gunther Roland
sPHENIX Co-Spokesperson
Massachusetts Institute of Technology
Cambridge, MA 02139

Dear LANL LDRD Committee Members and other interested persons,

We are pleased to strongly support the proposal for Los Alamos National Laboratory Directed Research funding to develop an inner tracking technology for measuring bottom quark jets at sPHENIX. As the Co-spokespersons of the sPHENIX experiment, a new experiment at the Relativistic Heavy Ion Collider that is currently undergoing technical design development, we give the proposal our strongest endorsement and encourage its timely adoption.

The sPHENIX physics program is designed to investigate the scale dependent dynamics that underlie the properties of the Quark Gluon Plasma. The experiment is specifically mentioned as the top recommendation for our field in the 2015 Long Range Plan for Nuclear Science. The proposed measurement of bottom quark jets is directly aligned with the physics mission outlined in the Long Range Plan. The installation of the sPHENIX detector construction is scheduled to start in 2019, with data taking beginning in 2022. To ensure a successful measurement of bottom quark jets, research and development on the precision inner tracker should begin as soon as possible. We believe the LANL team's proposal is essential to this pillar of the sPHENIX mission.

The team in P-25 has previously constructed important detectors for PHENIX, including the Muon Tracker and Forward Vertex detectors. Dr. Michael McCumber, the Frederick Reines Fellow on the PHENIX team, has an excellent track record of accomplishment and is extremely well-regarded in the collaboration. He is one of the primary authors of twelve PHENIX physics papers, and has represented the PHENIX collaboration numerous times in talks at international conferences. Mike's deep involvement in the sPHENIX proposal led to his invitation to present the case for "Updated jet performance and algorithmic approaches" at the successful DOE review of the sPHENIX science case in April 2015. He has taken a leading role in pursuit of the state-of-the-art tracking solution required by the sPHENIX science aims.

This proposal will have a critical impact on the experimental output of the sPHENIX experiment and is strongly complemented by contributions from LANL theorists. Calculations of b-jet observables, including intra-jet observables, are needed for guiding development of the future RHIC program. The LANL theorists on the proposal

Argonne NATIONAL LABORATORY

Donald F. Geesaman
Distinguished Argonne Fellow

Physics Division
Argonne National Laboratory
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Argonne, IL 60439-4845

1-630-252-4059 phone
1-630-252-3903 fax
geesaman@anl.gov

May 5, 2016

Letter of Support for the LDRD proposal "Probing Quark-Gluon Plasma with Bottom Quark Jets at sPHENIX"

This LDRD proposal addresses an extremely important avenue of research in the physics of the hot, dense state of matter that is the strongly coupled quark-gluon liquid. Heavy quarks shed new light on the physics because, by the nature of the large b quark mass, they immediately bring a hard scale to the dynamics. The scientific impact of these studies have been documented in numerous publications. To date studies of b quark dynamics at RHIC have been limited primarily to bottom-antibottom pairs, the Upsilon particles, as the existing detectors did not have the resolution and coverage to measure displaced vertices sufficiently well. This proposal addresses the major experimental issue of finding a suitable precise and low mass detector technology with an order of magnitude improvement in spatial tracking resolution and also the rapidly advancing theoretical issues of jet physics in the complicated RHIC environment.

Successful completion of this detector R&D would almost certainly place LANL to lead the construction of a major state-of-art detector component at RHIC and also elsewhere. It certainly would be an incredibly valuable technology for the Electron-Ion Collider (EIC) that was identified in the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plan as the highest priority for new facility construction in nuclear science in the United States. I led this Long Range Plan as the Chair of NSAC and I can assure you of the commitment of the community to both the heavy ion and the EIC science.

The LANL groups have demonstrated the scientific and technical skills necessary to carry out this R&D in both the experimental and theoretical areas. They are among the world leaders in heavy quark physics in the quark-gluon plasma. The synergy of the two efforts will ensure the focus on the optimum science goals.

This LDRD project will be exceptionally valuable for LANL, nuclear science, and the nation.

Sincerely,

Donald F. Geesaman

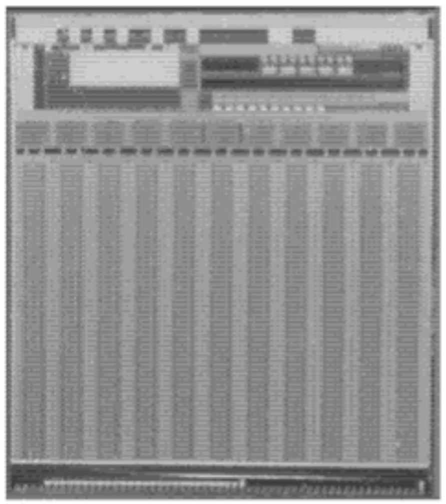
"We give the proposal our strongest endorsement and encourage its timely adoption"
~ our Spokespersons

"This LDRD project will be exceptionally valuable for LANL, nuclear science, and the nation."
~ Donald Geesaman

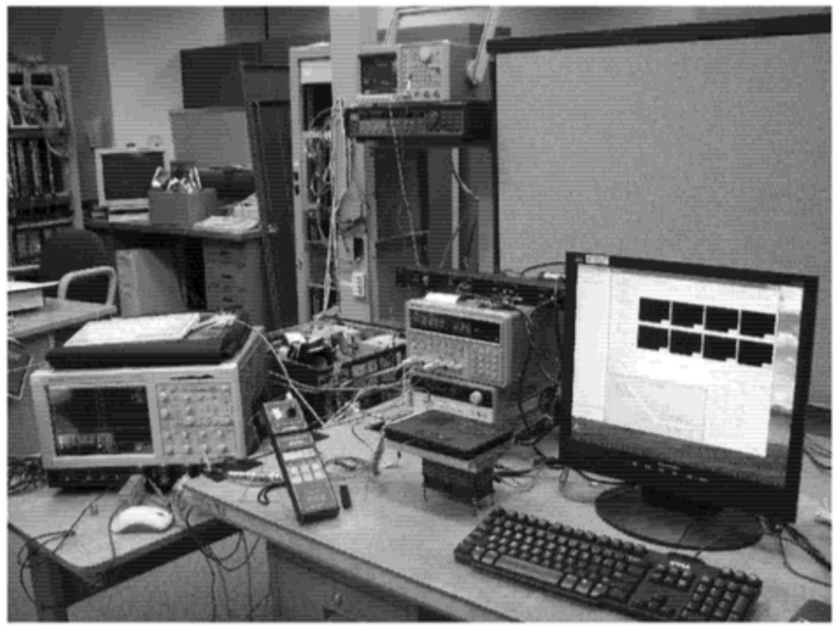
LDRD Strategy

Previously successful path followed by the LANL's FVTX

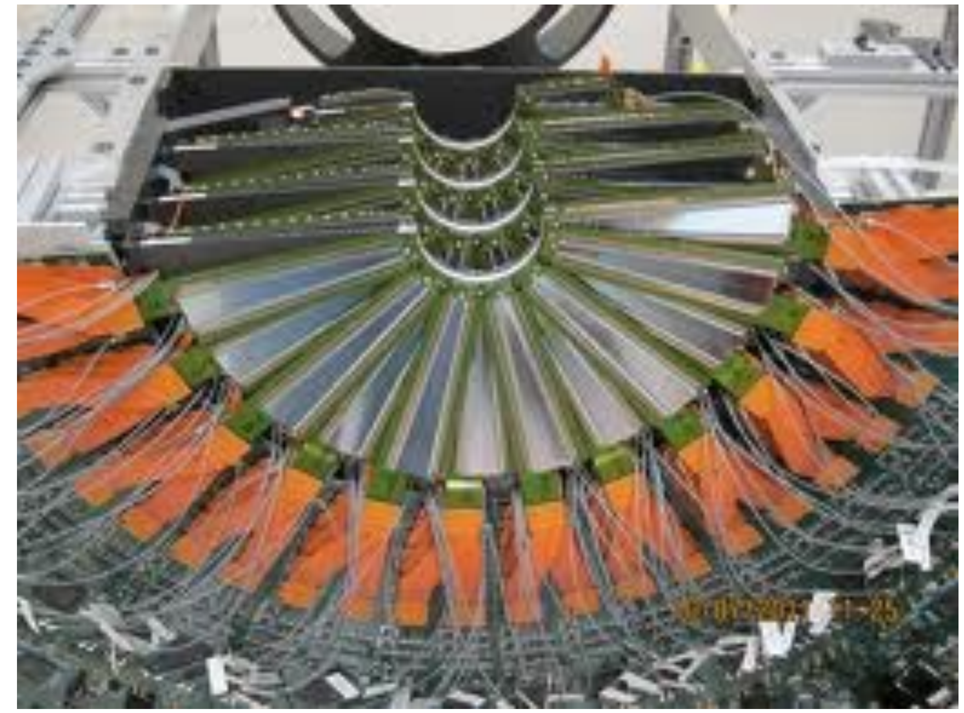
prototyping under LDRD DR:



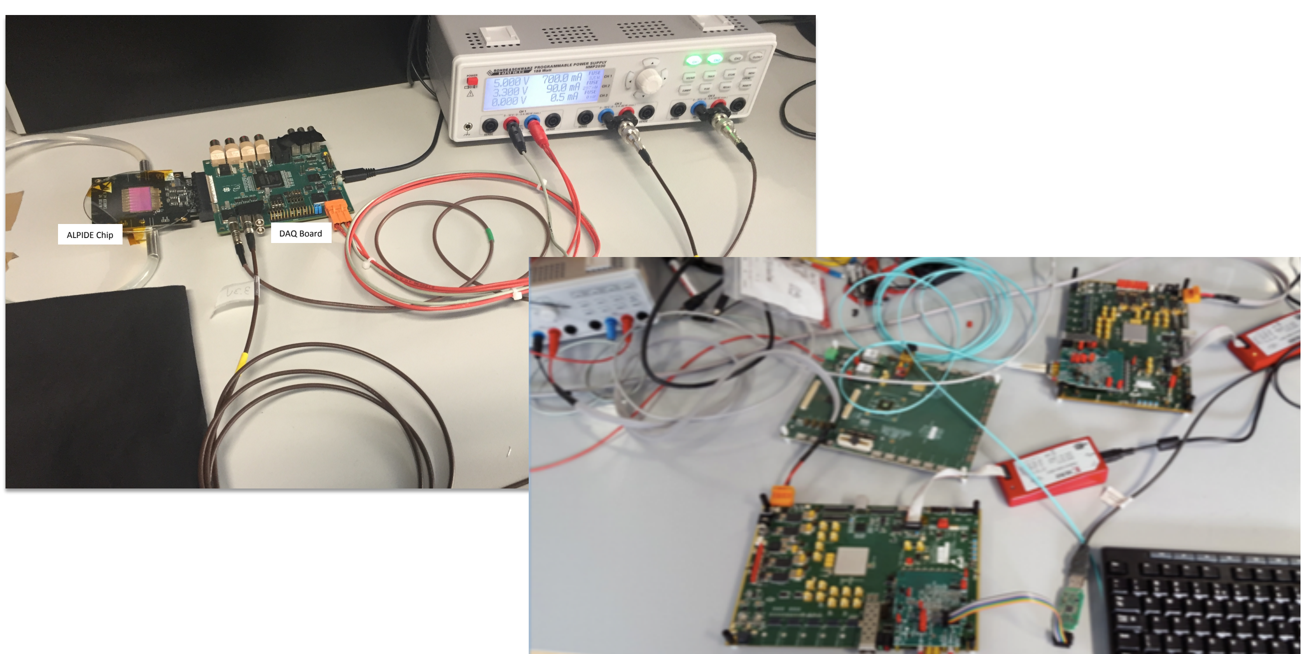
prototype pixel sensor

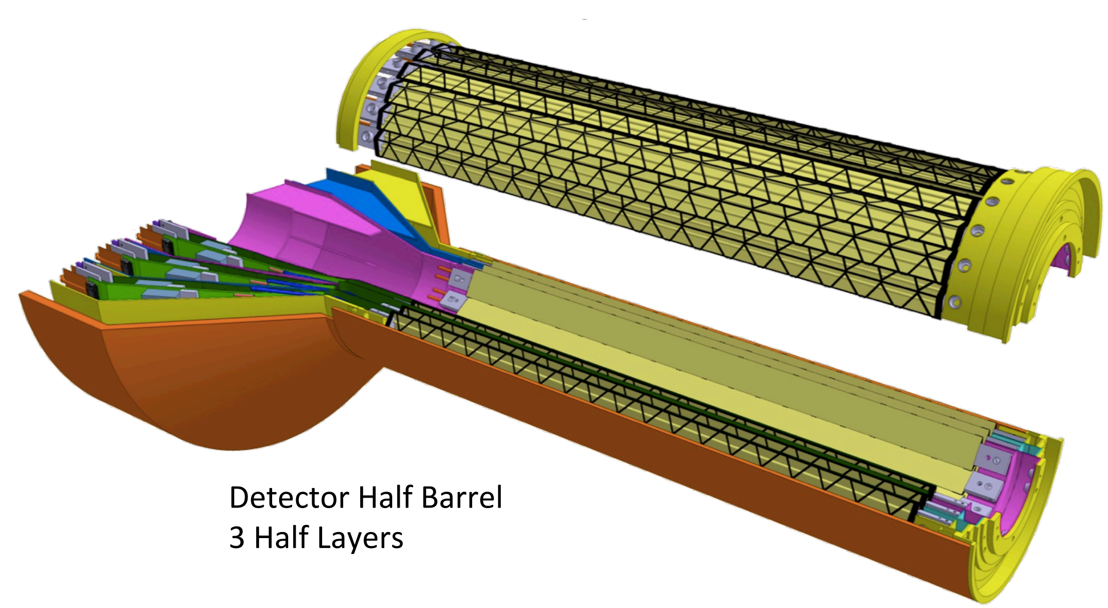


final tracker support from DOE:



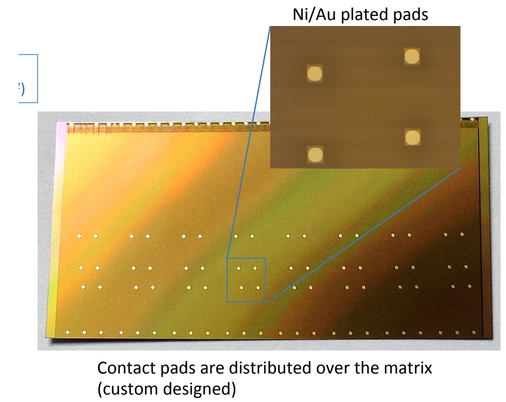
this is a proven successful strategy for securing a leading role in Big Science





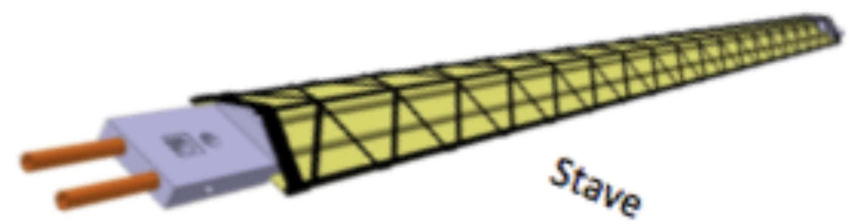
LDRD Hardware Deliverables

Extend TowerJazz Production:
  In-kind contribution
  525 ALPIDE-3 sensors
  (inner 3 layers plus ~20% spares)



525 ct.

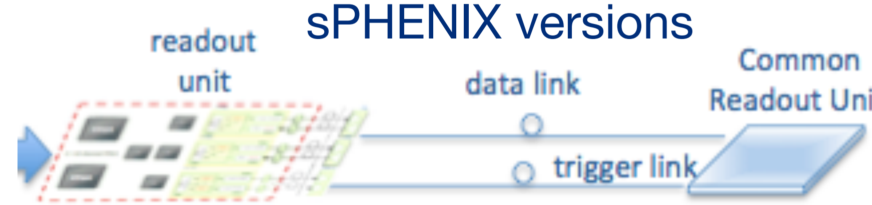
Test Beam Prototype:
  4 full inner ALICE ITS Staves
  ALICE readout + common readout boards
  small scale power & cooling, jigs, etc



4 ct.

Readout Design:
  new FEM design for sPHENIX,
  replace the ALICE readout board
  full-system test with test beam prototype

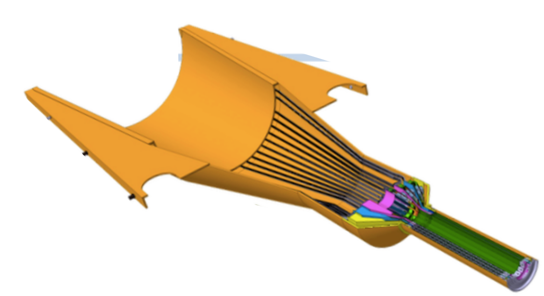
sPHENIX versions



4 ct.

Half-Barrel Mechanical Design:
  adapt ALICE inner 3 layer mechanics to sPHENIX
  build 3-layer mounts for full-system test

sPHENIX versions



2 ct.

Under LDRD funding:
  Final Detector ~10% populated with staves & readout
  CERN-trained personnel
  Reduce cost of MAPS detector

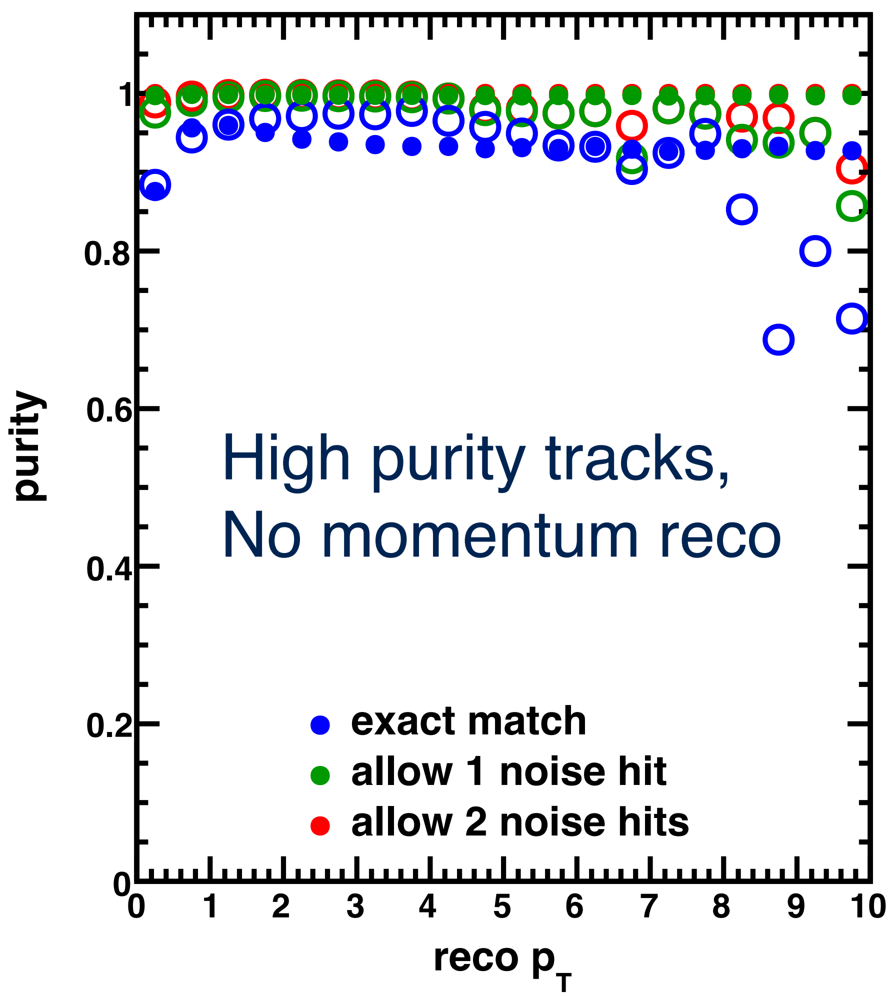
Ongoing Investigations

ALPIDE3 Prototype Sensor at Los Alamos

Joanna Szornel (works in Leo's lab) visited us from LBL May 2-4

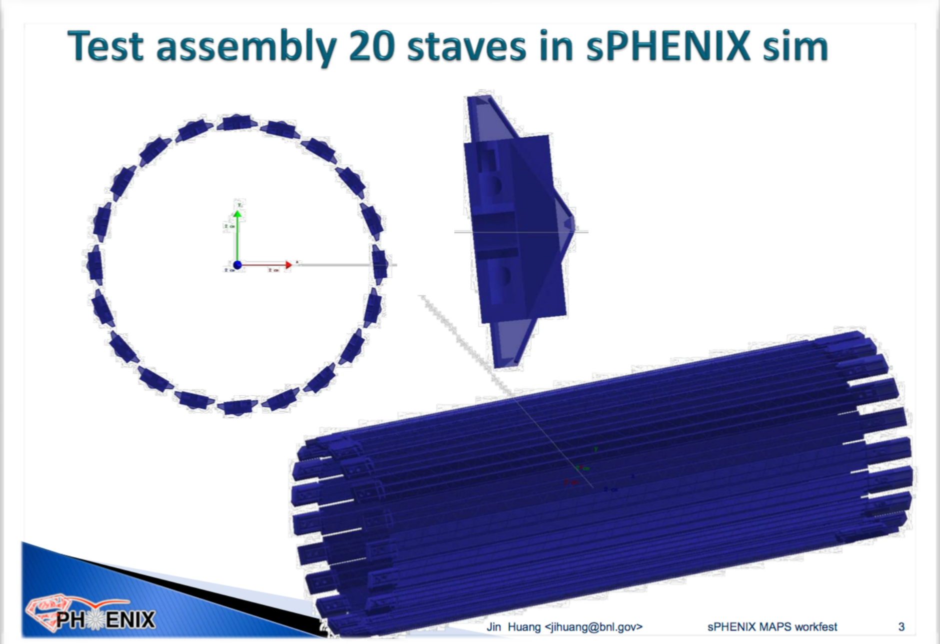
Guided us through the chip tests
Showed us how to run single-event upset tests
Helped workout the binary packet spec
Planned out how to build a run control library for RC-DAQ

Standalone Tracking Capabilities



High purity standalone tracking
=> easy alignment procedure
=> detector characterization

Extended Software Efforts



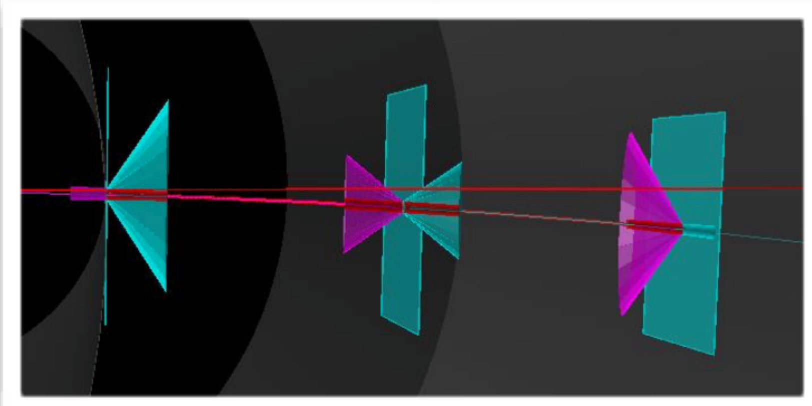
(i) realistic stave/ladder geometries

(ii) generic kalman tool

(a) fits with realistic geos (handle MS in cooling lines)

(b) split track merger (handle shingling)

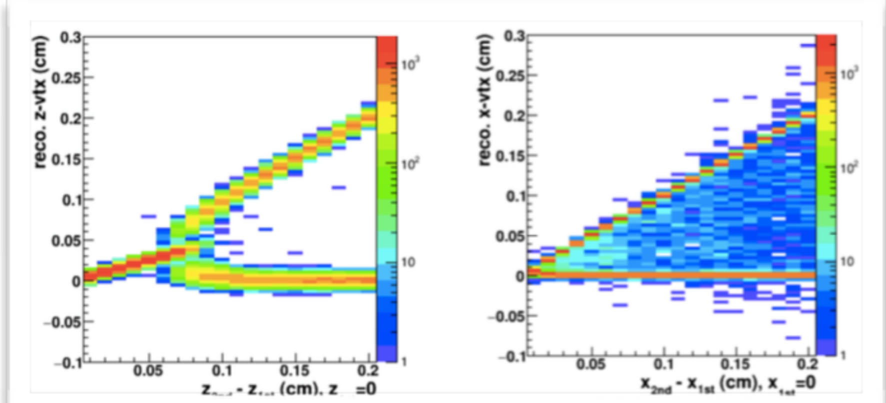
(c) primary track fits (aka use the vertex)



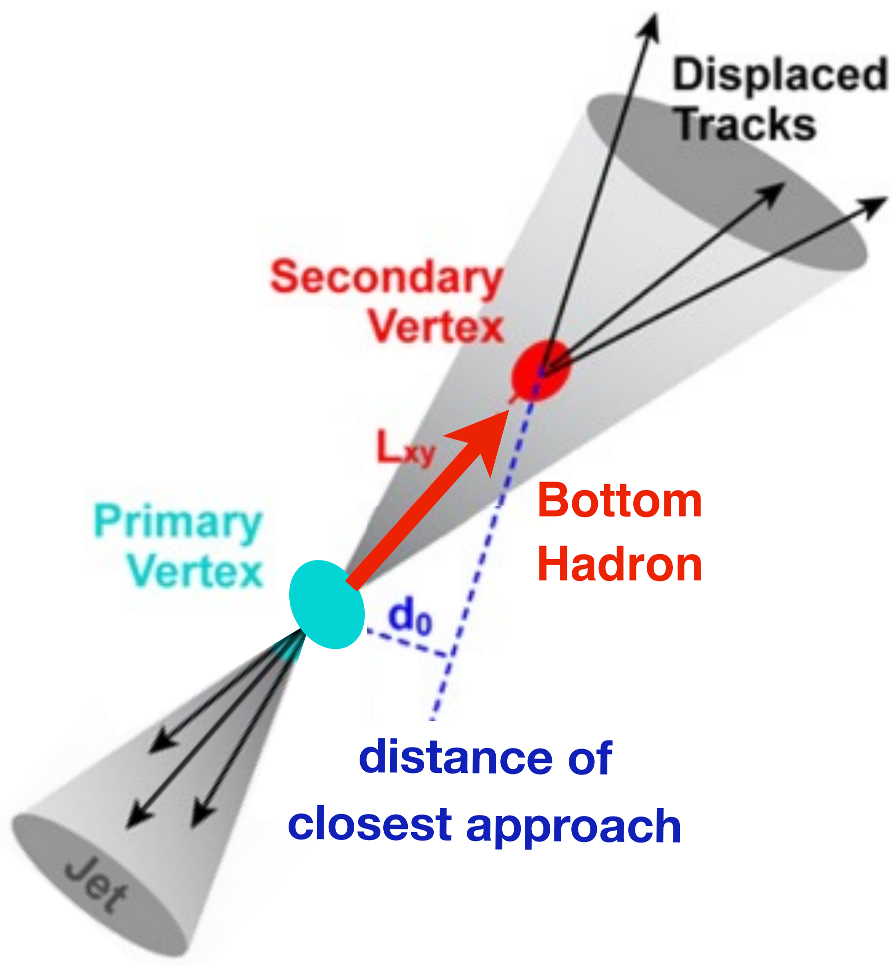
(iii) multiple vertexing with RAVE tool

(a) secondary vertex b-jet identification

(b) multiple collisions vertexing



Summary

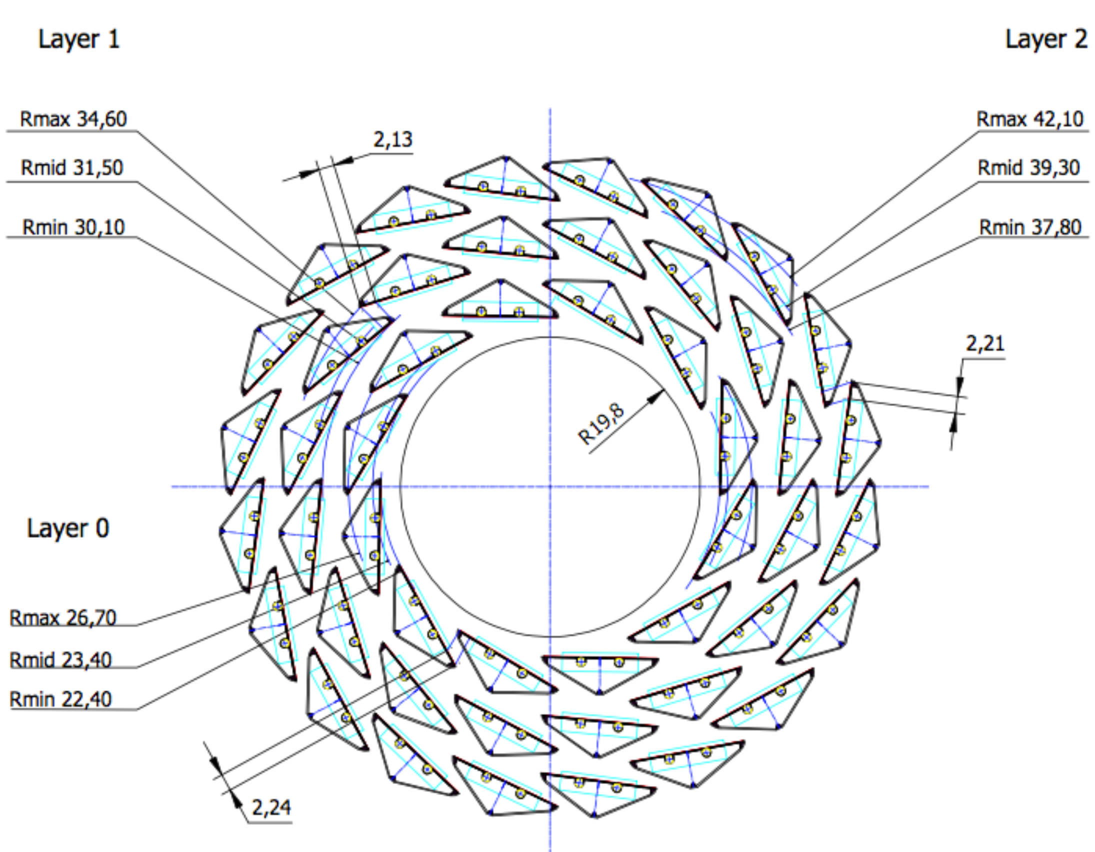


Most viable approaches to **bottom identification**: track counting and 2nd vertexing both **require highly efficiency tracking**.

R&D from the LHC upgrades has improved greatly on pixel dimensions (important for 2nd vertexing) and efficiency.

sPHENIX should greatly benefit from these developments, to ignore them will imperil our physics output.

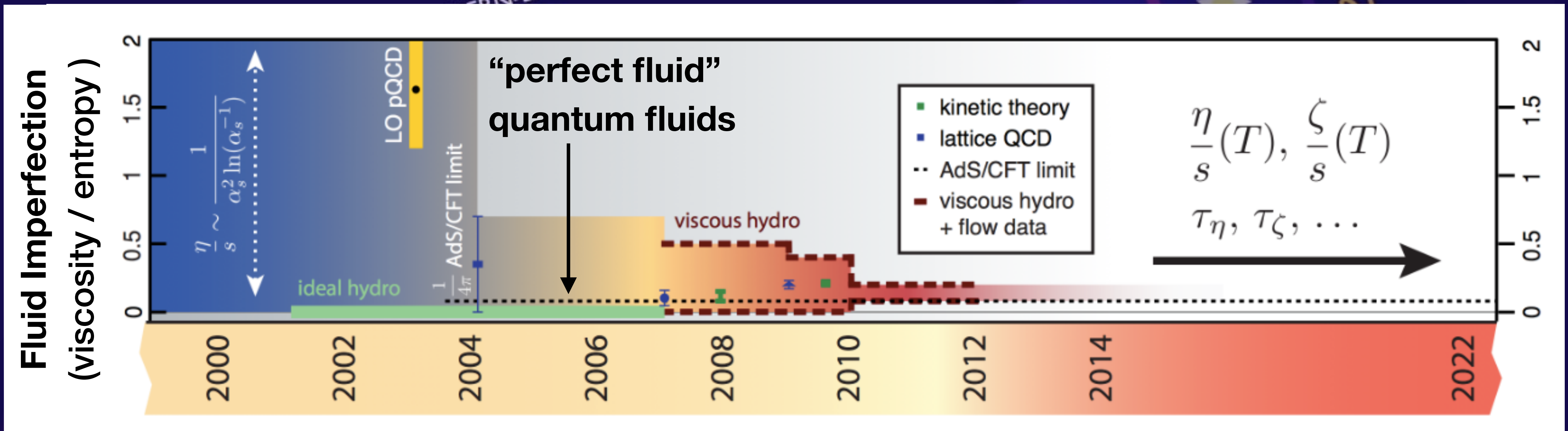
A new set of innermost tracking layers will ensure that heavy flavor jets remain the 3rd pillar of the sPHENIX program.



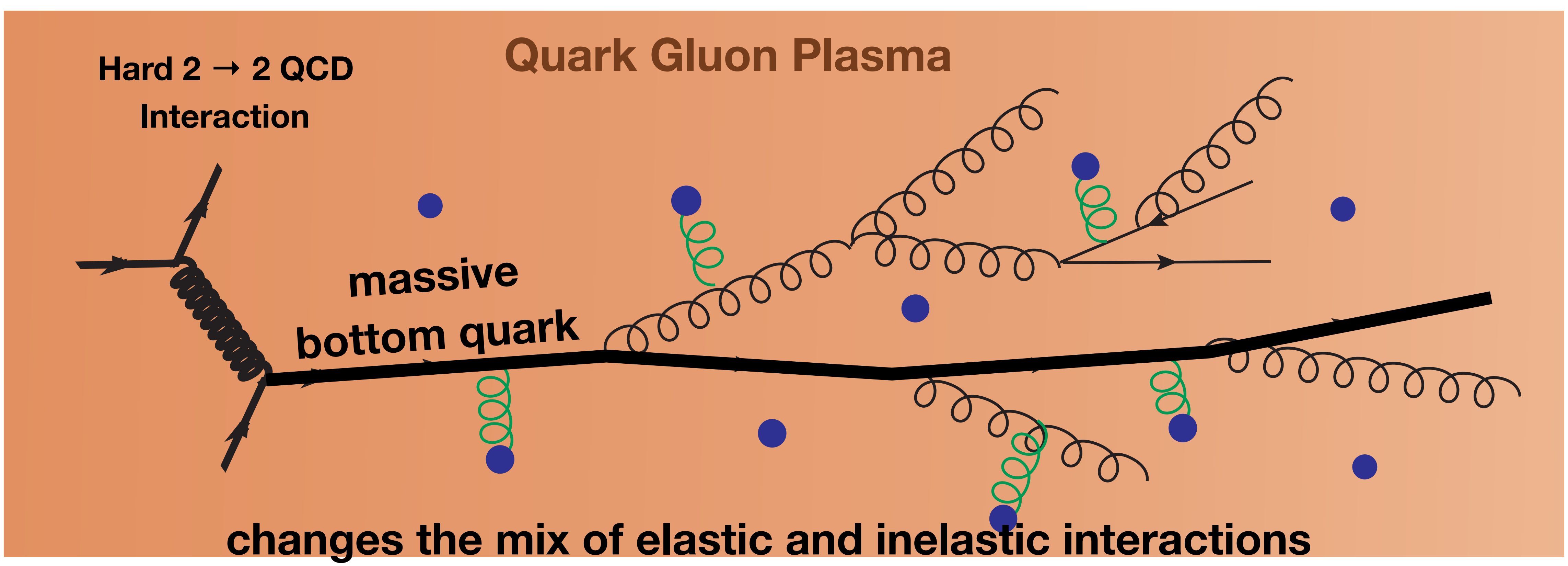
Thank you!

Backup Slides

Macroscopic Picture of the Quark Gluon Plasma



Microscopic Picture of the Quark Gluon Plasma ??



Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Interconnection of pixel chip to flex PCB

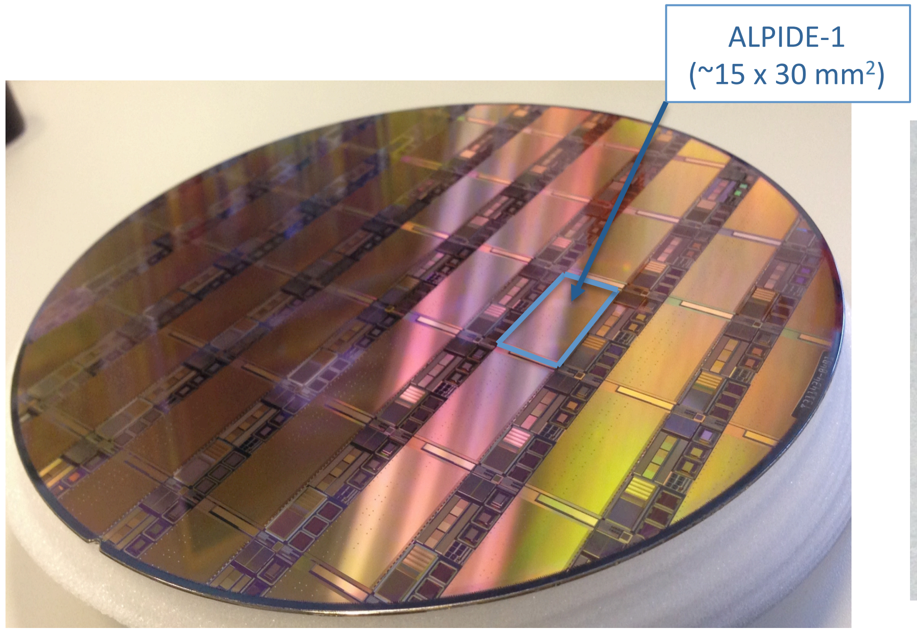
A Large Ion Collider Experiment

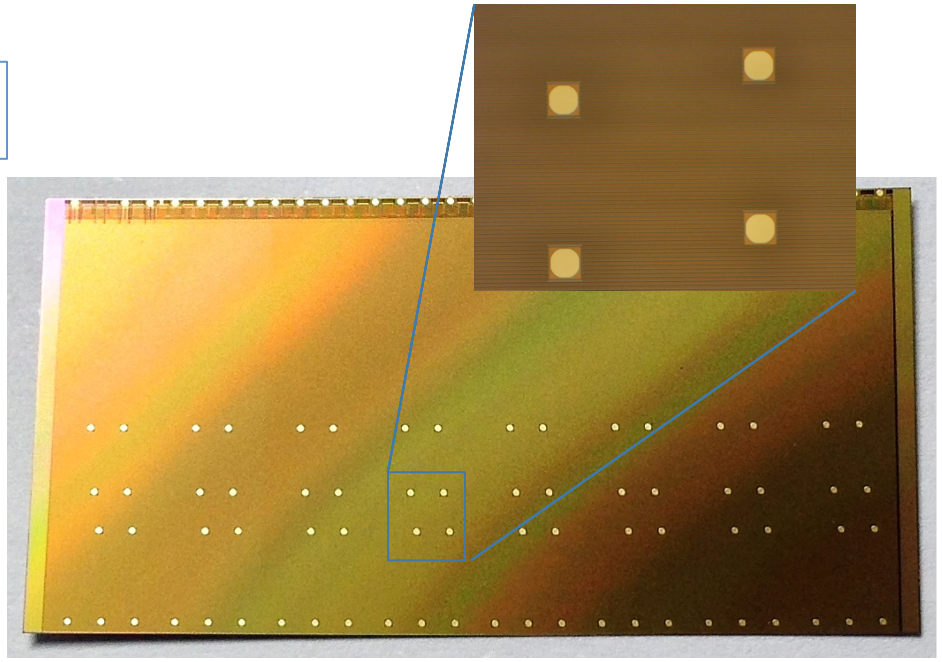
ALICE

Solder Pads

In order to solder the chip on the flexible printed circuit (FPC), the chip Al pads need to be covered with Ni-Au (wet-able surface)

Plating is done on wafers level using electroless Ni-Au plating, prior to thinning and dicing



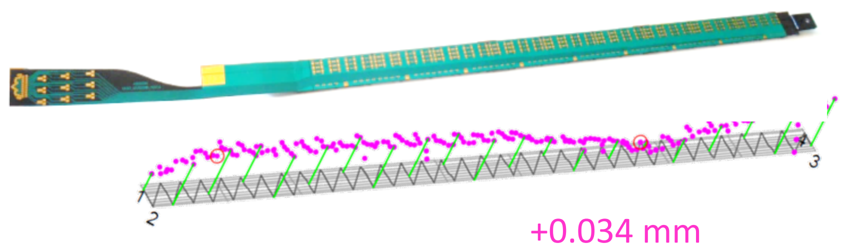


Contact pads are distributed over the matrix (custom designed)

Inner Barrel Stave

Stave HIC+ Space frame assembly

Dimensional accuracy

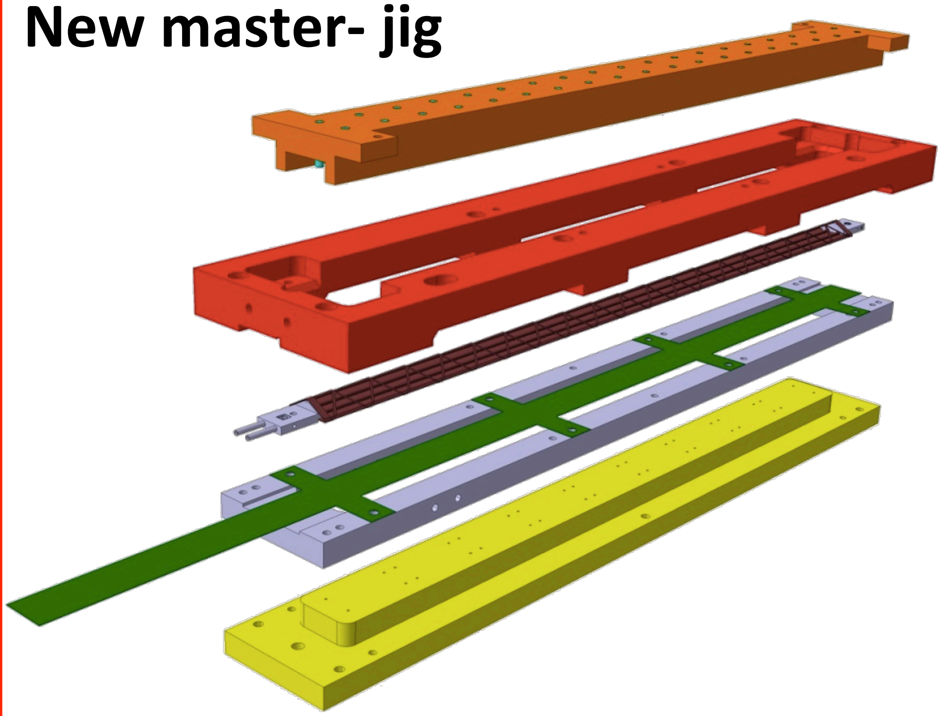


+0.034 mm
- 0.034 mm

status

New master jig (ready) will improve stave accuracy

New master- jig



ongoing

New master jig produced and shipped from the Company, metrological verification ongoing

Space frame production

status

Available : n. 20 spaceframe

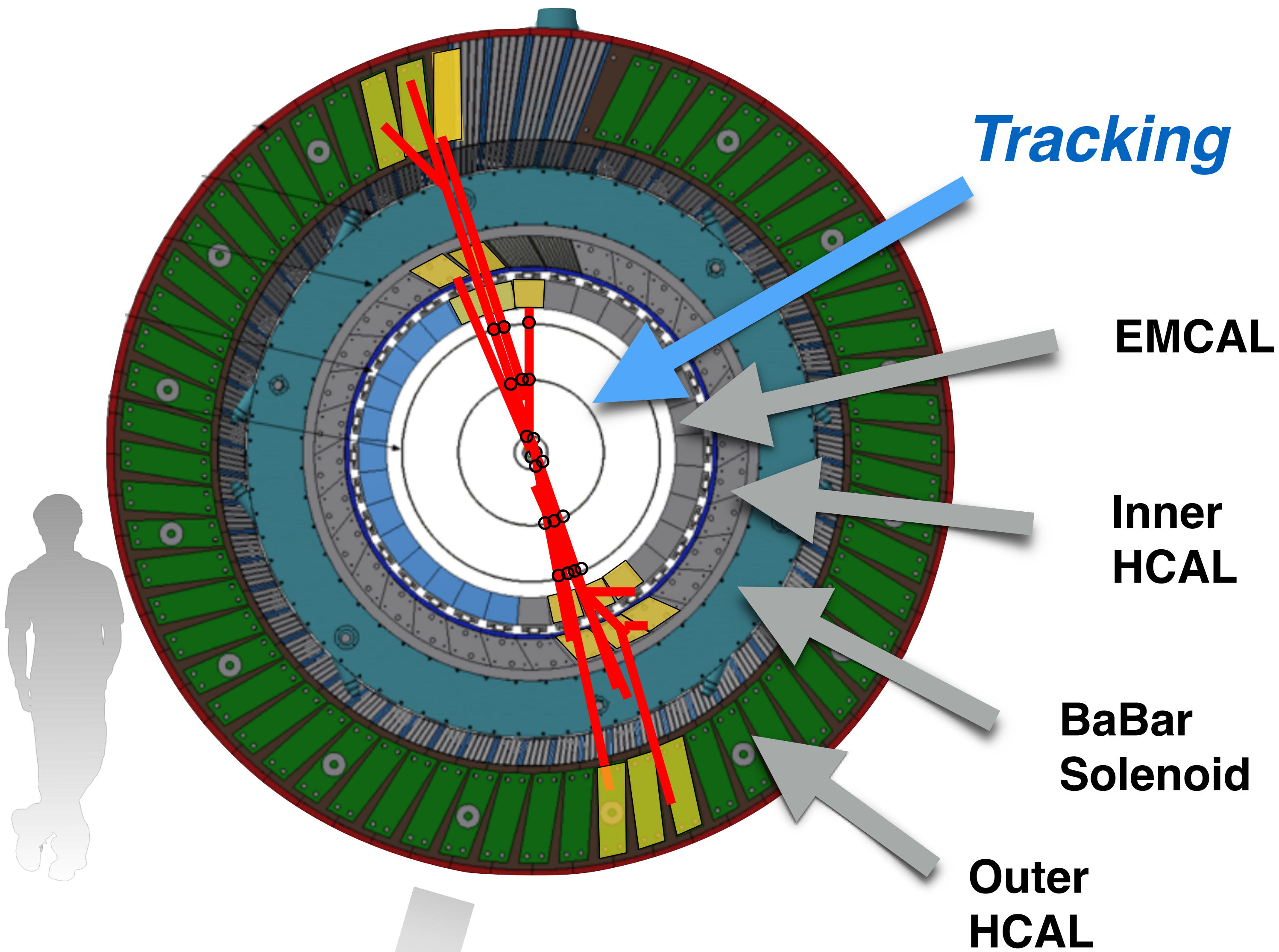
Ongoing

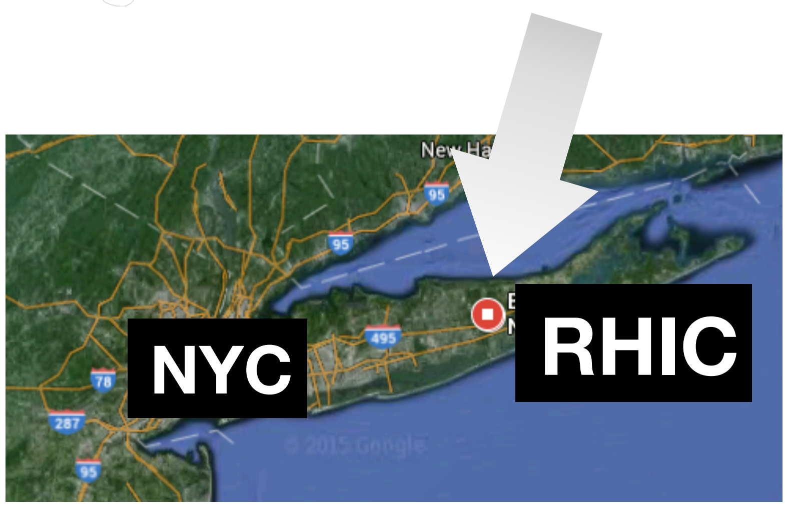
pre-production continues to prepare for final series production

Layout and curing process optimization: planarity achieved ± 0,028÷0,040 mm

sPHENIX Proposal: nucl-ex/1501.06197

Jets and Upsilons at RHIC in 2021 & 2022





Physics: *study of QGP structure over a range of length scales and temperatures with* ***hard-scattered probes inc. bottom quark jets***

"[sPHENIX] presented ***a compelling physics program.****"*
~ sPHENIX DOE Science Review Committee

sPHENIX ***highlighted in Hot QCD Long Range Plan***

Inaugural Collaboration Meeting
Rutgers Dec 10-12th, ***~60 institutions***